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RELATION OF NONEXCHANGEABLE POTASSIUM AND MAGNESIUM TO DEVELOPMENT IN SOME IOWA SOILS

by

John Alvis Kovar

A Dissertation Submitted to the
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Approved:

Signature was redacted for privacy.

In Charge of Major Work

Signature was redacted for privacy.

Head of Major Department

Signature was redacted for privacy.

Dean of Graduate College

Iowa State University
Of Science and Technology
Ames, Iowa

1967

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DEDICATION

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INTRODUCTION

This study was undertaken to learn more about the "thin loess-over-till" soils of the Dinsdale and Sac sequences of eastern and northwestern Iowa. This group of soils was recently separated at the series level and very few studies have been conducted on them. This investigation should give a better understanding of the genesis and morphology of these soils and provide a firmer basis for their classification at the series level.

In eastern Iowa there are approximately 500,000 acres included in the Dinsdale sequence of soils and approximately 450,000 acres in the Sac sequence in northwestern Iowa.[1] The thin loess/till soils also occur extensively in eastern Illinois, western Indiana and southwestern Ohio.

The main emphasis of this study will be on the thin loess/till soils of Iowa, and some soils formed in similar parent material from Illinois and Ohio will be included so the climate and parent material factors can be evaluated on a regional basis. These soils are forming in 20 to 40 inches of loess over glacial till. The prairie (grassland) soil series are dominant in Iowa; in Illinois and Ohio the forest series are most common. In addition the thick loess (>45 inches of loess) soils of the Tama sequence and the surficial sediment (<20 inches of friable, loamy sediments/till) soils of the Kenyon sequence will be used for an evaluation of the parent material differences in eastern Iowa.

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[1]Acreage figures are from tabulation of conservation needs in Iowa by counties. R. I. Dideriksen, Assistant State Soil Scientist, Soil Conservation Service, Ames, Iowa. Personal communication. 1967.

The nonexchangeable potassium and magnesium relationships of the $<1\mu$ clay fraction of these soils are emphasized in this study. It is thought that the processes of weathering, leaching and recycling of these ions are important in characterizing the genetic soil formation and development processes in these soils. Though only a limited number of studies have been conducted on the nonexchangeable potassium and magnesium status of Iowa soils, they indicate that these forms are primarily dependent on climate, or the amount of weathering that the soils have undergone. Other factors such as parent material, vegetation, drainage and the stage of development of a soil also have an influence on these relationships. In addition to nonexchangeable potassium and magnesium, laboratory analyses to be conducted are: particle size analysis, sodium tetraphenylboron extractable potassium, exchangeable potassium and magnesium and x-ray diffraction.

Specifically, the objectives of this study are to:

1. Evaluate the nonexchangeable potassium and magnesium status of the clays of the thin loess/till soils and determine what, if any, relationships exist between these ions and soil development.

2. Propose some possible explanations for the nonexchangeable potassium and magnesium profile variations and the related leaching and recycling processes.

3. Compare the effects of different climate, vegetation, drainage and parent material on the nonexchangeable potassium and magnesium status and attempt to attribute various differences to each of the above factors.

4. Evaluate the sodium tetraphenylboron extractable potassium and

x-ray diffraction data and determine if any relationships exist between these and the nonexchangeable potassium status.

5. Evaluate the data and relationships in terms of soil classification, and determine if there are chemical and clay mineralogical criteria which can be used as an aid in series separation and characterization of the Sac and Dinsdale series.

BACKGROUND

History of the Sac and Dinsdale Series

The thin loess/till soils of Iowa is a recently separated group of soil series that was formerly included with other series. They were included with and classified as Marshall series in the 1905 Tama County Soil Survey Report (Ely *et al.*, 1905). In the Black Hawk County Soil Survey Report (Tharp and Harper, 1919) the major loess soil is called Tama and described as approximately 35 inches of loess over till. In the Grundy County Soil Survey Report (Jones and Carson, 1925) the thin loess over till soils were called Carrington. Brown (1936) classified the soils with some loess over till as Carrington, both in northwestern and eastern Iowa. In the Osceola County Soil Survey Report (Orrben and Swenson, 1940) thin loess/till soils were called Marshall (till substratum). As the knowledge concerning these soils increased the need for a separate group of soils became apparent. About 1950 the well drained, prairie thin loess/till soils of northwestern Iowa were tentatively named Sac (Riecken and Smith, 1949) or soil number 77 in Soil Conservation District mapping (Barnes *et al.*, 1953). During this period the well drained, prairie thin loess/till soils of eastern Iowa were designated as "shallow Tama-like", or as soil number 377 (Barnes *et al.*, 1953) and named Dinsdale in 1960 (U.S. Soil Survey Staff, 1966). Series naming of the drainage and vegetative associates of Sac and Dinsdale is in the tentative stage at present.

Environmental Features of the Region

According to the latest Pleistocene map of Iowa by Wright and Ruhe (1965) the two areas of occurrence of the thin loess/till soils of Iowa correspond closely to the areas that have been known as Iowan till. These authors state that the Iowan Stage or Substage first was thought to be a separate stage of the Pleistocene, but later was considered the earliest substage of the Wisconsin Glaciation. Current detailed geomorphic and stratigraphic studies, supported by drilling (Ruhe _et al._, 1965) indicate that the landscape for the classic Iowan drift in eastern Iowa is a multi-leveled sequence of erosion surfaces and that many of these levels cut into Kansan and Nebraskan till. These studies fail to show the presence of Iowan drift, and indicate that the classic Iowan drift is actually an erosion surface of the older Kansan or Nebraskan till which has been mantled in places by loess. The loess that covers the classic Iowan drift was formerly called Peorian, but is now called Wisconsin loess (Ruhe, 1954). Radiocarbon dates from the basal part of the thicker loess indicate that the age of the material at this point is approximately 20,000 to 25,000 years old. The thinner loess over till is considered to have been deposited between 14,000 and 20,000 years ago (Ruhe _et al._, 1965).

On the basis of these studies the Dinsdale series and its sequence associates have the following parent material relationships. The Kansan and/or Nebraskan drift underwent erosion during a period approximately 20,000 years ago. Concurrent with erosion loess was deposited on and stabilized some of the surfaces. The Dinsdale and its sequence associates occur where the loess deposit is approximately 2 to 3 feet thick. Typically these areas have gently sloping to level topography. As loess deposition occurred prior to 14,000 years before present, B.P., the parent materials of the Dinsdale sequence have been subjected to soil formation for approximately 14,000 to 20,000 years (Ruhe et al., 1965).

The sediments in northwestern Iowa have been discussed by Simonson et al. (1952) and Smith and Riecken (1947). These sediments were first considered to be Iowan drift, but later evidence indicates that the eastern portion of the area was covered by the Tazewell glacier. The Iowan and Tazewell drifts were considered the first and second substages of Wisconsin glaciation, but the Iowan drift is now in doubt as discussed by Ruhe et al. (1965) and Wright and Ruhe (1965). The Tazewell sediments in northwestern Iowa are approximately 20,000 years old (Wright and Ruhe, 1965). The Sac soils occur where the loess is approximately 20 to 40 inches thick, mostly over loam Tazewell drift. Presumably this loess was deposited during the same period as that from which the Dinsdale soils formed.

Ruhe and Scholtes (1956) state that climatic environments in the past probably were different from present conditions. During Late Sangamon (>25,000 years B.P.) and Wisconsin time (24,000 to 11,000 years B.P.) the soil landscapes were dominantly forested under a cool or cold, moist climate. A warmer, grassland environment may have occurred in mid-Wisconsin time (15,000 to 13,500 years B.P.), and a cool moist arboreal environment may have culminated approximately 5,000 years ago. A warmer, subhumid to humid prairie environment became dominant at that time.

Walker (1966) investigated the stratigraphic zones of some bogs within the Des Moines lobe of Cary glaciation. The pollen and macrofossil data from these stratigraphic zones indicate that forest vegetation was prominent on the landscape until approximately 8,000 years ago, and subsequently, herbaceous prairie flora dominated the landscape up to the time of settlement. Soils developed in this area show profile properties that relate to the last 3,000 years of prairie environment.

Davidson (1961) states that the estimates of original forest cover were from less than one-eight to one-fifth of the total land area. According to comparisons of the 1859 and 1954 surveys of forest resources, the forested land has decreased approximately 61 percent.

Soils of the Sac sequence are a part of the Galva-Primghar-Sac Soil Association (Oschwald et al., 1965) which occurs in northwestern Iowa as shown in Figure 1. Soils of the Sac sequence are primarily in the nearly level to gently sloping areas, and are forming where the Wisconsin loess (Ruhe, 1954) is 20 to 40 inches thick over glacial till. Other soils of the sequence are shown according to drainage and vegetation in Table 1. The average annual rainfall in this area is about 26 to 28 inches as shown in Figure 1. The native vegetation was almost exclusively tall grasses (Holowaychuk, 1960; Oschwald, 1965).

Soils of the Dinsdale sequence are a part of the Dinsdale-Tama Soil Association (Oschwald et al., 1965) which occurs in eastern Iowa as shown in Figure 1. These soils are also minor inclusions in the Tama-Muscatine and Kenyon-Floyd-Clyde Soil Associations which occur in the same area (Figure 1). Soils of the Dinsdale sequence occur mainly on

Figure 1. Map of Iowa showing soil association areas considered in this study (Oschwald _et al._, 1965) and average annual precipitation (Elford, 1959) for the state

Soil associations

GPS	Galva-Primghar-Sac
DT	Dinsdale-Tama
TM	Tama-Muscatine
KFC	Kenyon-Floyd-Clyde

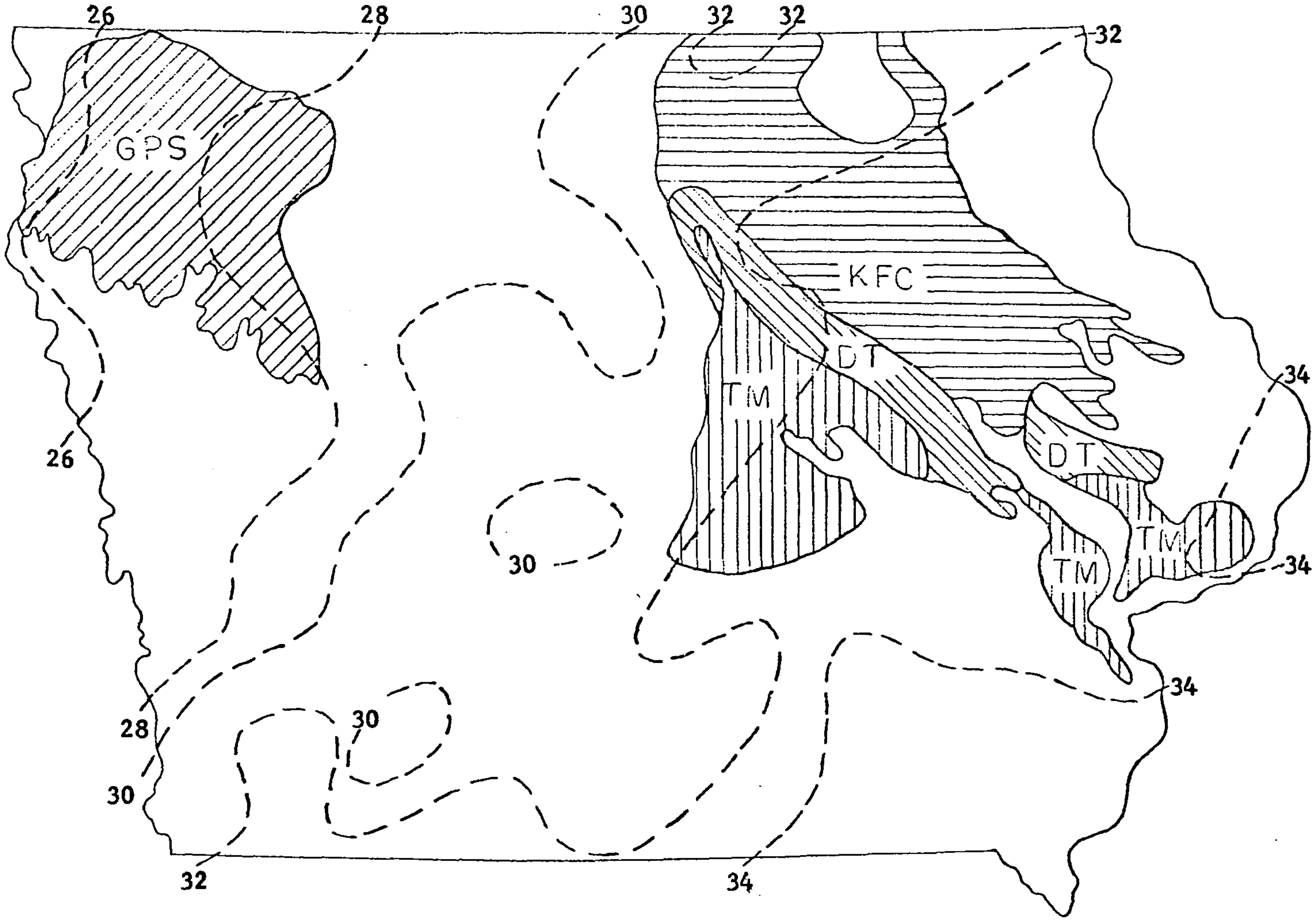
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Table 1. Parent material, vegetation and topography (drainage) relationships of the soils studied

Parent material and area	Vegetation	Topography (drainage)		
		Well drained	Somewhat poorly drained	Poorly drained
Thin loess/till	Prairie	Sac	P737 (soil no. 282)	P738 (soil no. 191)
(20-40 inches)	Prairie/forest	(soil no. 77SF)[a]	P736 (soil no. 282F)	
northwestern Iowa	Forest			
Thin loess/till	Prairie	Dinsdale	Klinger	Maxfield
(20-40 inches)	Prairie/forest	Waubeek	Franklin	
eastern Iowa	Forest	P739 (soil no. 481)		
Thick loess	Prairie	Tama	Muscatine	Garwin
(>40 inches)	Prairie/forest	Downs	Atterberry	Walford
eastern Iowa	Forest	Fayette	Stronghurst	Traer
Surficial sediments	Prairie	Kenyon	Readlyn	Tripoli
over till (<20 inches)	Prairie/forest	Racine-Bassett[a]	Oran[a]	
eastern Iowa	Forest	Renova-Coggon[a]		
Thin loess/till	Prairie	Sidell[a]	Dana-Raub[a]	Chalmers[a]
(20-40 inches)	Prairie/forest	Mellott[a]	Wingate-Toronto	Romney[a]
Illinois-Ohio	Forest	Russell	Xenia-Fincastle	Delmar[a]

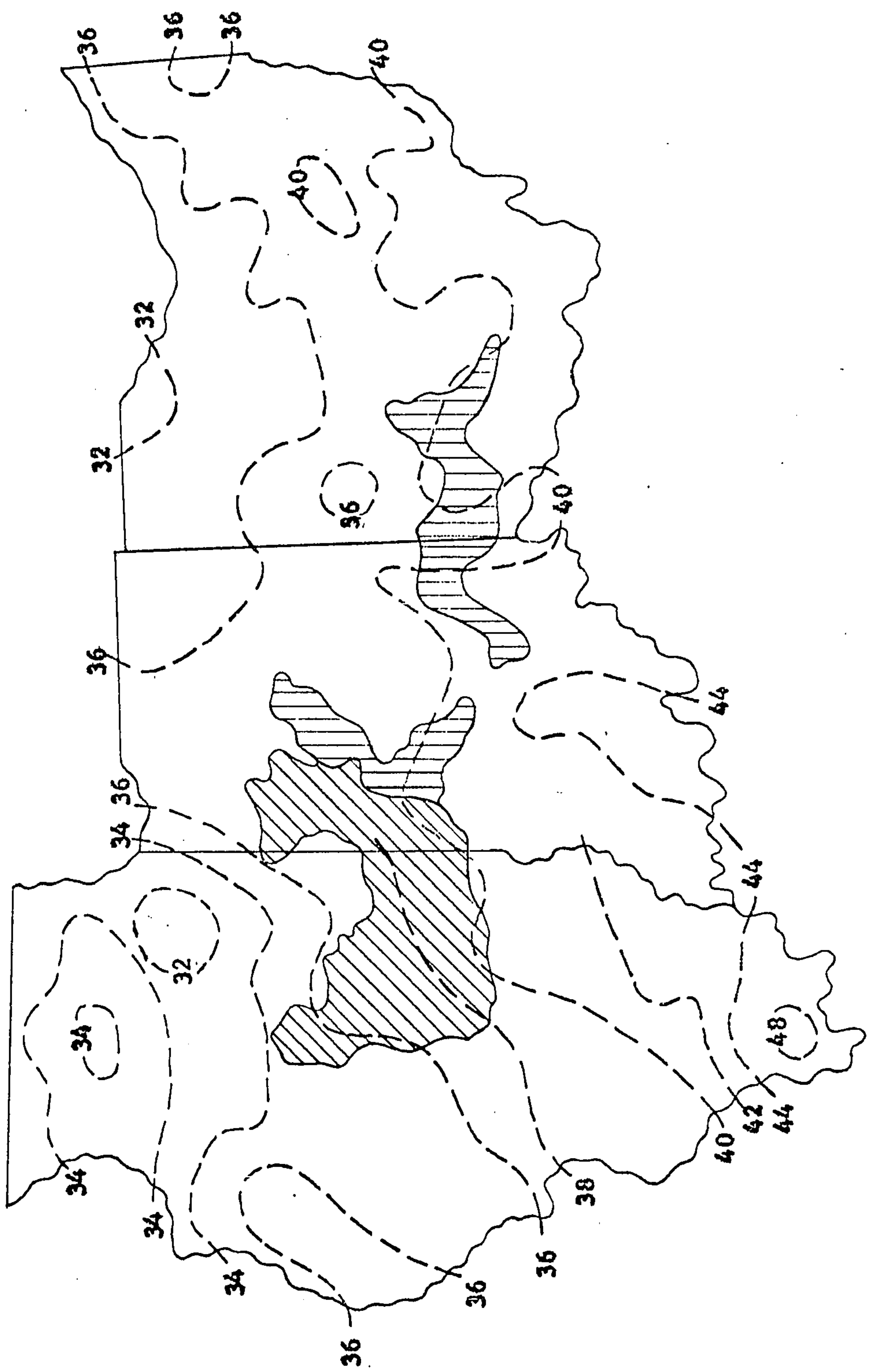
[a]These samples were not used in this study.

the nearly level to gently sloping areas and are developing where the Wisconsin (Ruhe, 1954) loess is 20 to 40 inches thick over Kansan or Nebraskan (Wright and Ruhe, 1965) till. There are six series presently recognized in this sequence and these are arranged according to drainage and vegetation in Table 1. The average annual rainfall is about 32 to 34 inches in this area (Figure 1). The native vegetation was primarily tall grasses; although, some rather extensive areas were influenced by forest or mixed prairie/forest vegetation (Holowaychuk, 1960). The associated soils are the Tama sequence which is forming in >40 inches of loess and the Kenyon sequence which is forming in 20 to 30 inches of surficial loamy sediments over till. The individual series of these sequences are arranged according to drainage and vegetation in Table 1.

The soils of the Russell sequence (Table 1 and Figure 2) of eastern Illinois and southwestern Ohio are also forming in thin loess/till (Ulrich, 1960 and Wascher *et al.*, 1960). The average annual rainfall in the areas of occurrence is about 37 to 39 inches in Illinois and about 39 to 41 inches in Ohio. The native vegetation was primarily forest; although, some extensive areas had prairie vegetation in Illinois.

The thin loess/till soils of Illinois are in the part of the state invaded by the Early Woodfordian stage of Wisconsin Glaciation (Frye *et al.*, 1965 and Willman *et al.*, 1963). This till is mantled with Richland loess (Wisconsin) that is about 20,000 to 22,000 years old at the base of the loess. Wilman *et al.* (1963) state that the Wisconsin tills have a higher content of potassium feldspars, magnesium silicates and illite than the older tills. The high content of illite is attributed

Figure 2. Map of Illinois, Indiana and Ohio showing the thin loess/till soil association areas (Aandahl *et al.*, 1960) and average annual precipitation (Joos, 1959; Pierce, 1959 and Schaal, 1959) for these states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to the fact that the Wisconsin Glaciation advanced from the northeast across an area that is characteristically rich in these minerals.

General Nature of the Soils

The well drained prairie soils of the Dinsdale and Sac sequences generally have a dark brown to black, silty clay loam surface approximately 9 to 18 inches thick. They have a yellowish brown silty clay loam upper subsoils. The poorer drained associates have a black, silty clay loam surface approximately 15 to 20 inches thick with grayish brown to gray, silty clay loam upper subsoils. A stone line frequently occurs at the junction of the loess and till. Thin sand lenses are also common between the loess and till and may extend as wedges into the upper part of the till. The subsoil in till and the substratum is generally loam in texture. The soils of the Dinsdale sequence are generally free of carbonates to 50 or 70 inches, but those of the Sac sequence are usually calcareous below 30 or 40 inches.

Soil Forming Factors and Processes in this Region

The character of the soils of an area is the result of the environmental conditions of climate, vegetation and physiography which control the interrelationships and rates of the soil forming processes. According to Holowaychuk (1960), the extent of their effects on the parent materials varies with the nature of the material and the ages of the landscapes (time). The soils of the areas studied are classified as

Brunizem, Gray-Brown Podzolic and Humic-Gley great soil groups. Also there are Brunizem—Gray-Brown Podzolic and Humic-Gley—Gray-Brown Podzolic intergrades which are combinations of the former groups.

The Brunizems, formerly called Prairie soils (Thorp and Smith, 1949), consist of the well and somewhat poorly drained soils developed under grass vegetation. According to the 7th Approximation system (U.S. Soil Survey Staff, 1960) these soils are called Udolls (see Table 2 for classification). These soils have formed under the dominant influence of prairie vegetation in an environment of humid, continental climate, but on landscapes of varying form, age, and parent material (Oschwald et al., 1965; Riecken, 1960, and Smith et al., 1950). Riecken (1960) states that the major soil forming processes in the Brunizems are: the accumulation of organic matter in the surface layer, leaching of bases and development of acidity in the A and B horizons, the formation of a high cation-exchange capacity clay, and the accumulation of this clay in the B horizon. The degree of expression of these processes varies greatly depending primarily on the parent material, physiography and age of the landscape. Smith et al. (1950) discuss the genesis of Brunizems and state that the Prairie soils of the Upper Mississippi Valley region have developed under relatively uniform climatic and biotic influences, but on a wide variety of parent materials. They consider accumulation of organic matter, leaching of carbonates from surface horizons, formation of 2:1 lattice clay minerals, movement of fine clay downward with subsequent cessation due either to physical limitations or to flocculation by electrolytes, and reduction in percent base saturation with increased leaching to be the major processes which result in formation of Prairie soils. Barshad (1946) observed that regardless of the great variation in mineralogy of different California Prairie soils, the nature of the variation in composition of colloids with depth is alike. This indicates that a unique process or set of processes takes place in Prairie soil (Brunizem) formation which overrides the effects of parent materials.

The Gray-Brown Podzolic soils have developed in a humid, temperate climate, from variable parent material under deciduous forest consisting primarily of oak and hickory with some beech and maple (Bailey et al., 1964; Oschwald et al., 1965; Ulrich, 1960 and Wascher et al., 1960). Under free drainage these soils have a thin organic and organic-mineral layers over a grayish-brown leached layer which rests upon an illuvial brown horizon. The primary soil forming processes in these soils are the addition of organic matter to the A0 and A1 horizons, the removal of soluble materials such as carbonates and exchangeable bases from the solum, the formation of silicate clays from other silicates, the movement of silicate clays and associated sesquioxides from the A horizons and their accumulation in the B horizons. Changes in the structure include the development of crumb structure in the A1, platy structure in the A2 and angular or subangular blocky structure in the B horizons. Bailey et al. (1964) reported that Gray-Brown Podzolic soils are more weathered and more developed than the Brunizem—Gray-Brown Podzolic intergrades. This is based on the higher organic carbon content and base status of the A1 horizons; higher clay maxima, higher cation-exchange capacities, lower

Ca/Mg ratios and lower base status in the B2 horizons of the Gray-Brown Podzolic soils.

The Humic-Gley soils, formerly called Wiesenbodens, are important associates of the Brunizem and Gray-Brown Podzolic soils. The Humic-Gley soils have formed under grass or sedge vegetation in grassland areas and under sedge or swamp hardwood forest in forested areas on sites which are poorly drained, but not wet enough for the formation of organic soils (Aandahl, 1960). These soils generally have a thick, very dark gray to black, usually noncalcareous A1 horizon underlain by a mottled, olive gray Bg horizon and a mottled, olive gray C horizon. The primary soil forming processes in these soils are the accumulation of organic matter, some leaching of bases and development of characteristics associated with wetness such as low chroma colors and mottles. The excess water restricts the oxygen in the soil pores which causes reduction, and segregation and removal of the iron compounds which produces the olive gray subsoil.

Potassium Relationships

Several investigators have studied the potassium relationships in soils. Wells (1963) analyzed the $<1\mu$ clay fraction of the B horizons of some loess derived soils and concluded that the nonexchangeable potassium, K, content decreases from west to east across the region as average annual rainfall increases. In explaining the K distribution it was found from a mineralogical study that the 10Å clay minerals decreased from west to east along with a corresponding increase in the 17Å clay minerals.

This was interpreted as an indication, assuming the micaceous clay minerals to be the primary source of potassium, that as weathering of these clays takes place, the K is depleted and montmorillonites are formed. Wells also studied the potassium release with sodium tetraphenylboron and found that the soils of southwestern Iowa release more potassium per unit time than similar soils from southeastern Iowa, indicating that potassium relationships could be used as a criterion for soil classification.

Bray (1934, 1936, 1937), Hutton (1951), Jenny (1931), Jones and Beavers (1966) and White et al. (1960) studied the nonexchangeable potassium, K, relationships in soils. Generally it was concluded that most of the nonexchangeable potassium is in the interlayer position of the micaceous clay minerals. Downward movement of the finer particles leaves the surface horizons richer in potassium; whereas, the clay accumulative B horizon becomes richer in iron and magnesium. Nonexchangeable potassium was found to decrease with increasing soil development which usually coincides with increasing rainfall. The nature of the parent materials affects the rate of leaching of the potassium, and this is an indicator of climatic factors operating during soil formation. The more westerly soils of the midwestern region were found to contain more potassium than the eastern soils and the differences were attributed to a higher rate of weathering in the eastern part of the region due to more rainfall. Bray (1937) states that physical weathering in the surface apparently breaks down the more easily broken beidellite-type materials containing no potassium and leaves the mica relatively more concentrated in the coarse colloidal fraction in the more weathered stages of soil development.

Corliss (1958), Daniels (1956), Hanway et al. (1960) and Ulrich (1951) studied exchangeable potassium, K^+, relationships in Iowa soils. Data indicate exchangeable potassium is related to soil development, based on decreasing loess thickness and increasing distance from the loess source. This coincides with increasing rainfall from west to east across the state. No definite relationship between the clay mineral composition and exchangeable potassium is evident. Milford and Jackson (1966) concluded that differences in the content of clay size mica were closely related to the wide differences in the content of exchangeable potassium in oven-dried samples.

Pratt (1952), Rausell-Colom et al. (1965), Reed and Scott (1966), Scott and Reed (1962a, 1962b), and Scott and Welch (1961) studied potassium release in some Iowa soils both by short-term intensive cropping and sodium tetraphenylboron release. McClelland (1951) studied the release of bases from some primary minerals found in soils. These studies show that time, temperature, particle size and composition of materials all affect the release of potassium. At first potassium is released rapidly, but the rate diminishes progressively. The clay fraction contributes about 60 percent of the potassium released. Short-term cropping is similar to chemical methods of potassium release, but if given enough time, plants will remove more potassium than chemical methods. The rate and amount of release of ions tends to approximate the content present in the unweathered mineral. Generally the release of bases from minerals is accompanied by the breakdown of the crystal lattice of the mineral, but the release of potassium appears to proceed faster than decomposition to the mineral. There is no evidence of a change in the charge density of illite when up to 68 percent of the potassium is removed. The slow rates of natural weathering in soils is attributed to excess potassium in solution, or essentially an accumulation of weathering products.

Magnesium Relationships

Protz (1965) determined the nonexchangeable magnesium, Mg, in the <1μ clay fraction of loess-derived soils along a traverse from eastern Nebraska across Iowa to western Illinois. He showed that Mg correlates with distance from west to east along the traverse, and the soils are an expression of climate, primarily precipitation, over the region studied. He considers that before clay moves downward, Mg is being depleted from the clay, and lattice breakdown occurs at the edges. The processes take place in the following order: formation of clay, alteration of clay as indicated by Mg content, and movement of clay. This is based on data which show that the most developed soils indicate maximal movement of clay and an increase of Mg and 17Å/7Å ratios with depth.

Bray (1937) reported that nonexchangeable magnesium content of a soil decreases with increasing development, and that magnesium content does not vary much with the size of the colloidal fraction. He proposed various stages of soil development based on the magnesium content.

Several investigators have studied the exchangeable magnesium in soils. Bray and DeTurk (1930) concluded that when pH drops below 5, exchangeable magnesium exceeds exchangeable calcium and vice versa for a group of Illinois soils. Their data indicate that soils tend to have high exchangeable magnesium when the parent material is high in that ion. Ulrich (1951) stated that the exchangeable calcium/magnesium ratio decreased with increasing soil development and that this is due to decreasing calcium rather than increasing magnesium. White and Riecken (1955) showed that the exchangeable calcium/magnesium in the B horizon is lower in the forested soils than in associated prairie soils.

Several investigators have conducted experiments in acid leaching and acid dissolution of clay minerals as a means of determining the rate of ion release from these materials. Kerr *et al*. (1956) stated that highly dissociated protons in acid clay attack the lattice, and there is a simultaneous release of magnesium and the formation of a weak silicic acid which is part of the lattice structure. Since the release of the Mg ion precedes the release of silica, proton attack is most probably occurring at the lattice edge rather than at the silicate surface. As the lattice is attacked at the edges, the newly exposed edges are identical to the edge structure prior to degradation, and the remainder of the lattice is unaltered. Osthaus (1956) concluded that the rate of dissolution reactions are nearly the same for Al, Fe and Mg ions in octahedral coordination, but the rates in the octahedral layer are significantly different from the rates in the tetrahedral layer. On this basis he determined the ion content within the octahedral and tetrahedral coordination and stated that an increase in temperature or acid concentration resulted in a proportional increase in the dissolution rate. Barshad (1960a, 1960b) states that H ions replace Mg ions in the octahedral layer of the clay lattice and the Mg becomes exchangeable. This conclusion is based on the fact that the filtrate of water and carbonate water leached samples were free of Mg and Al ions; whereas the filtrates of HCl leached samples had considerable Mg, Ca and Al ions. He postulates that H ions from the clay surface or exchange complex enter the interior of the lattice and displace the ions from the octahedral coordination. This suggests that chemical alteration and breakdown of silicate minerals proceeds beyond the first stages of hydrolysis. The amount of interchange is dependent on the crystal structure or ease of accessibility to the sites of the octahedral Mg ions, the particle size and perfection of crystallization in addition to the total MgO content. Coleman and Craig (1961) hydrogen saturated and decomposed montmorillonite and found that Al and Mg ions moving from lattice positions to exchange sites proceed at a rate approximately proportional to the content of these ions in the unaltered clay. Soluble silica is a concurrent product of the alteration and this suggests that these reactions are similar to natural weathering processes. Caillere and Henin (1965) cite evidence that alteration of the tetrahedral layer of mica is not initiated until after almost complete destruction of the octahedral layer.

Clays and Clay Minerals

Several investigators have studied the weathering sequence of clay minerals. Jackson _et al._ (1948) state that the weathering sequence of clay size minerals proceeds through thirteen stages, each represented by a type mineral, but one or more of the intermediate stages may be absent at a given time. Three to five of the minerals from a sequence may be present in a horizon, but usually only one or two are dominant. One mineral may be the parent material for successive stages in the sequence. The weathering stage of a colloid is the resultant of factors such as temperature, moisture, acidity, particle size and nature of the materials. Generally the three major clay minerals weather in the sequence illite $\rightarrow$ montmorillonite $\rightarrow$ kaolinite. Jackson _et al._ (1952) postulate that as weathering of micas proceeds through illite, intermediates and montmorillonites, the major chemical reactions taking place are: depotassication, hydroxylation, dealumination and desilication. Various combinations of clay minerals in various stages of weathering account for the differences in properties. Johnson and Jeffries (1957), White (1950), White _et al._ (1960) and Willman _et al._ (1963) discuss data supporting this weathering sequence of Jackson. Caillere and Henin (1965) state that by convention clay consists of particles smaller than 2μ and are comprised of several species of clay minerals. These minerals may be formed by a division of larger particles and may or may not be followed by structural modifications that maintain the essentials of elementary sheets. These changes are considered diagenesis. By contrast a complete dissolution of primary minerals and formation of clay minerals by secondary crystallization may be termed neogenesis. Keller (1964) states that materials and energy are important in clay mineral formation, and that climate and material are descriptive of the process and product only to the degree with which they affect the chemical system. He points out that montmorillonite forms under conditions of a high Si to Al ratio and a relative abundance of Mg, Ca, Fe, Na, and K ions with a low H ion concentration. Kerr (1955) considers that clay minerals are not original products of magmatic crystallization, but form subsequently by processes which involve at one extreme the action of compressed water vapor and related magmatic fluids at temperatures of several hundred degrees centigrade, and at the other extreme the action of atmospheric agencies at ordinary temperatures. Clay formation and alteration in soils primarily involves processes of the latter extreme which includes leaching, deposition and weathering. The clay minerals form slowly and various physical and chemical conditions may produce different types of clay minerals. The surrounding environment including climate, topography and vegetation has a great influence as well as the nature of the original sediments.

Cady (1960) points out that clay minerals in a soil are inherited from the parent material, formed in place or moved there from another part of the profile. Clay mineral distribution in the various horizons of the profile are affected by weathering, clay movement and other soil forming processes.

The clay mineral content of soils and parent materials has been investigated by several authors. Peterson (1946) showed that the soils of Iowa with parent materials of Pleistocene origin are characteristically high in montmorillonite, and the montmorillonite to kaolinite ratio varies according to climate, vegetation, and source and age of the parent materials. Soils forming in Pennsylvanian clay or shale are predominantly kaolinite. According to Hanway et al. (1960) x-ray data indicate that the Iowa soils studied contain montmorillonite, illite, kaolinite and chlorite, but montmorillonite is the dominant clay mineral. They found differences in the content of the various clay minerals between profiles and between horizons within a profile, but no consistent relationships were evident between clay mineral content and exchangeable potassium. Russell and Haddock (1941) estimated from chemical and thermal methods that the average content of montmorillonite, illite and kaolinite is 60, 30 and 10 percent respectively, in 5 Iowa soils. Beavers et al. (1955) state that montmorillonite is the most abundant clay mineral in the loess-derived soils, and illite and chlorite are the most abundant clay minerals in the unweathered Wisconsin till of Illinois. Evidence indicates that variations in the kind of clay minerals in the soils of Illinois are primarily the result of different parent materials and, to a much lesser extent, are the result of weathering processes. Weathering, however, increases the amount of clay and in some instances varies the proportion of the various clay minerals. White et al. (1960) concluded that the dominant clay mineral of the parent materials in glacial tills of Indiana is probably illite.

Weathering reactions consist primarily of alteration of the micaceous minerals to produce partially or completely expanding products, namely montmorillonite or vermiculite. Topography and drainage influence the proportion and distribution of the resulting clay mineral composition. Profiles having good internal drainage have a higher proportion of vermiculite to montmorillonite in the upper horizons than do soils with poor internal drainage.

Murray and Leininger (1956) state that montmorillonite is the dominant clay mineral in the more weathered upper portion of the Illinoian and Wisconsin tills, but the relatively unweathered portion of the tills contains illite and chlorite as dominant clay minerals. Glen et al. (1960) found that montmorillonite is the dominant clay mineral in Tama silt loam of Wisconsin. Illite is the second most abundant mineral in the clay, but is the most abundant in the coarse clay fraction.

Jackson (1959) postulates that the frequency distribution or relative abundance of clay minerals in soils varies with principal factors of soil formation. These factors exert an influence by introduction of the clay minerals directly, by controlling the chemical and physical weathering, by furnishing abundant divalent cations, by impediment of drainage, by acceleration of leaching when highly permeable, by intensity of climatic factors and by the type and relative abundance of organisms. Secondary layer silicate minerals such as montmorillonite, illite, chlorite, kaolinite and vermiculite are most abundant in the clays of moderately weathered soils of the midwest.

Soil Development

Soil development has been discussed by several authors. Wells (1963) studied the stage of development of the B horizons of soils along a traverse from eastern Nebraska to western Illinois and concluded that a climatic effect is operative which is related to degree and not kind of weathering. Depth to the middle of the zone of maximum clay accumulation was used as an index of stage of weathering to which the nonexchangeable potassium was related. As rainfall increased eastward, depth to the middle of the zone of maximum clay accumulation also increased as potassium content decreased. No consistent relationship was found between cation exchange capacity of the $<1\mu$ fractions and the indices of soil development. Ulrich (1950, 1951) and Hutton (1951) concluded that decreasing loess thickness and increasing distance from loess source account for the increase in development of the soils studied. Physical changes accompanying soil development are: increasing clay content in, and decreasing depth to, the maximum clay accumulation horizon; increasing formation, movement and accumulation of fine ($<0.06\mu$) clay; increasing volume weight; decreasing aeration and total porosity and decreasing permeability. Chemical data indicate that hydrogen is replacing other cations in the order: sodium > potassium > calcium > magnesium with increasing horizon differentiation. The exchangeable calcium/magnesium ratio decreases at virtually a straight line rate in the subsoil and upper substratum horizons with increasing development. Differences in parent material and variations in effective time of soil formation are primary causes of variation in development of soil profiles.

Hallsworth (1963), Brown _et al_. (1936) and Thorp _et al_. (1957) conducted laboratory experiments on simulated development of soils and clays. Clay is translocated from the surface downward by dispersion and eluviation. Movement of clay is restricted as the proportion present is increased and apparently ceases when a critical value is reached. However, this varies with the type of clay mineral and pH, but even at that level some clay moves into cracks that develop as the soil dries. In addition appreciable quantities of calcium, magnesium, iron and manganese were noted in the leachate. Evidence for redeposition of iron was noted, and colored bands suggestive of field soil horizons began to appear in the leaching columns.

Barshad (1964) states that in measuring changes resulting from chemical reactions a distinction must be made between reactants and the resulting products. The extent of reaction is determined by the amounts of reactants and products at the beginning and at the end of the reaction. One of the main reasons for failure to accurately analyze the reactants and products of soil lies in the difficulty of separating and clearly distinguishing between them. The methods of evaluating clay formation are based on the assumption that clay fractions are the products of weathering; whereas, the nonclay fractions are the reactants. The amounts of clay formed must be proportional, therefore, to the loss in those minerals of the nonclay fraction which alters to clay.

Previous Studies of the Thin Loess/Till Soils and Associates

Limited laboratory analyses including particle size distribution, organic matter content, cation exchange capacity and exchangeable cation content have been conducted on the Sac, Dinsdale and related soils by the Lincoln Soil Survey Laboratory (U.S. Soil Survey Staff, 1966). Particle size distribution data are listed in the Osceola County, Iowa Soil Survey Report (Orrben and Swenson, 1940). Foth and Riecken (1954) studied the properties of the Galva and Moody series of northwestern Iowa. White and Riecken (1955) investigated some prairie/forest transition soils forming in thick loess. Smith *et al*. (1950) discussed some prairie soils of the Upper Mississippi Valley. Phillips (1958) investigated the Floyd and related surficial sediment soils in northeastern Iowa. Bailey *et al*. (1964) investigated the properties of some forest-influenced thin loess/till soils of Illinois.

INVESTIGATIONS

This is a study of the thin loess/till soils of eastern and northwestern Iowa. Some thin loess/till soils of Illinois and Ohio are included to evaluate the regional parent material and climatic differences. Comparisons are made to the thick loess (Tama sequence) and surficial sediment (Kenyon sequence) soils of eastern Iowa to evaluate the parent material differences.

Field Methods

The criteria used in selecting soils for study, both of profiles previously sampled and those sampled for this investigation, are as follows: sites must be representative of the modal concept for the series, be on large fairly stable areas that have uniform topography. Further, the thin loess/till soils must have a low sand content in the loess portion of the solum, and the loess-till contact must be near the middle of the 20 to 40 inch range or about 30 inches plus or minus 2 inches.

The soils studied are given in Table 2 along with the locations and classification. Samples of some of the soils selected for this study were available from previous investigations. These previously sampled profiles fit the criteria set up for this study, so they were not resampled. They are noted and referenced in Table 2. The profiles sampled for this investigation include Maxfield (P733 and P734), Waubeek (P732 and P735), Franklin (P730 and P731), P739 (Unnamed soil

Table 2. Name, profile number, location and classification of the soils studied

Soil and profile number	Location	Native vegetation	Natural drainage class	Parent material	Great soil group	7th Approximation classification[a]	Reference
Sac I, P746 (11170-11177)[b]	Clay Co., Ia. Sec. 16, T95N R38W	Prairie	Well	Loess/till	Brunizem	Typic Hapludoll	(U.S. Soil Survey Staff, 1966)
Sac II, P747 (11178-11185)[b]	Clay Co., Ia. Sec. 28, T95N R37W	Prairie	Well	Loess/till	Brunizem	Typic Hapludoll	(U.S. Soil Survey Staff, 1966)
P737 (Unnamed soil no. 282)[c]	O'Brien Co., Ia. Sec. 15, T96N R40W	Prairie	Somewhat poorly	Loess/till	Brunizem	Aquic Hapludoll	--[d]
P738 (Unnamed soil no. 191)[c]	O'Brien Co., Ia. Sec. 1, T97N R41W	Prairie	Somewhat poorly to poorly	Loess/till	Humic-Gley	Aquic Hapludoll to Typic Haplaquoll	--[d]

[a]Classification is according to the latest list for Iowa and the North Central Region soils. R. I. Dideriksen, Assistant State Soil Scientist, Soil Conservation Service, Ames, Iowa. Personal communication. 1967.

[b]Lincoln Soil Survey Laboratory (USDA, SCS) number (U.S. Soil Survey Staff, 1966).

[c]This is a recently proposed series that is unnamed. It is identified by the mapping number.

[d]Soils sampled for this study with descriptions included in Appendix A.

Table 2. (Continued)

Soil and profile number	Location	Native vegeta- tion	Natural drainage class	Parent material	Great soil group	7th Ap- proxima- tion clas- sification[a]	Reference
P736 (Unnamed soil no. 282F)[c]	Clay Co., Ia. Sec. 20, T94N R36W	Prairie/ forest	Moderately well to somewhat poorly	Loess/ till	Brunizem— Gray-Brown Podzolic	Aquic Hapludoll to Typic Haplaquoll	--[d]
Dinsdale I, P704 (14194-14205)[b]	Black Hawk Co. Ia. Sec. 25, T87 R13W	Prairie	Well	Loess/till[e]	Brunizem	Typic Argiudoll	(U.S. Soil Survey Staff, 1966)
Dinsdale II, P705 (14205-14215)[b]	Grundy Co., Ia. Sec. 20, T88N R15W	Prairie	Well	Loess/till	Brunizem	Typic Argiudoll	(U.S. Soil Survey Staff, 1966)
Klinger I, P706 (14159-14167)[b]	Bremer Co., Ia. Sec. 33, T91N R12W	Prairie	Somewhat poorly	Loess/till	Brunizem	Aquic Argiudoll	(U.S. Soil Survey Staff, 1966)
Klinger II, P707 (14149-14158)[b]	Bremer Co., Ia. Sec. 26, T91 R12W	Prairie	Somewhat poorly	Loess/till	Brunizem	Aquic Argiudoll	(U.S. Soil Survey Staff, 1966)
Maxfield I, P733	Linn Co., Ia. Sec. 28, T84N R6W	Prairie	Poorly	Loess/till	Humic-Gley	Typic Haplaquoll	--[d]

[e]Loess/till refers to the group of soils that have 20 to 40 inches of Wisconsin loess over glacial till.

Table 2. (Continued)

Soil and profile number	Location	Native vegetation	Natural drainage class	Parent material	Great soil group	7th Approximation classification[a]	Reference
Maxfield II, P734	Linn Co., Ia. Sec. 30, T85N R6W	Prairie	Poorly	Loess/till	Humic-Gley	Typic Haplaquoll	--[d]
Waubeek I, P732	Iowa Co., Ia. Sec. 12, T81N R9W	Prairie/forest	Well	Loess/till	Brunizem—Gray-Brown Podzolic	Mollic Hapludalf	--[d]
Waubeek II, P735	Linn Co., Ia. Sec. 24, T83N R8W	Prairie/forest	Well	Loess/till	Brunizem—Gray-Brown Podzolic	Mollic Hapludalf	--[d]
Franklin I, P730	Linn Co., Ia. Sec. 28, T84N R6W	Prairie/forest	Somewhat poorly	Loess/till	Brunizem—Gray-Brown Podzolic	Udollic Ochraqualf	--[d]
Franklin II, P731	Iowa Co., Ia. Sec. 12, T81N R9W	Prairie/forest	Somewhat poorly	Loess/till	Brunizem—Gray-Brown Podzolic	Udollic Ochraqualf	--[d]
P739 (Unnamed soil no. 481)[c]	Linn Co., Ia. Sec. 15, T83N R8W	Forest	Well	Loess/till	Gray-Brown Podzolic	Typic Hapludalf	--[d]

Table 2. (Continued)

Soil and profile number	Location	Native vegetation	Natural drainage class	Parent material	Great soil group	7th Approximation classification[a]	Reference
Tama Pal-1	Grundy Co., Ia. Sec. 29, T87N R17W	Prairie	Well	Loess	Brunizem	Typic Argiudoll	(Fenton, 1966)
Muscatine P94	Tama Co., Ia. Sec. 3, T84N R15W	Prairie	Somewhat poorly	Loess	Brunizem	Aquic Argiudoll	(Corliss, 1958)
Garwin Pal-3	Grundy Co., Ia. Sec. 29, T87N R17W	Prairie	Poorly	Loess	Humic-Gley	Typic Haplaquoll	(Fenton, 1966)
Downs P428	Tama Co., Ia. Sec. 5, T85N R14W	Prairie/ forest	Well	Loess	Brunizem—Gray-Brown Podzolic	Mollic Hapludalf	(White, 1953)
Atterberry P608	Tama Co., Ia. Sec. 35, T84N R16W	Prairie/ forest	Somewhat poorly	Loess	Brunizem—Gray-Brown Podzolic	Udollic Ochraqualf	(Corliss, 1958)
Walford P607	Poweshiek Co., Ia. Sec. 23, T81N R14W	Prairie/ forest	Poorly	Loess	Humic-Gley—Gray-Brown Podzolic	Mollic Ochraqualf	(Corliss, 1958)
Fayette P32	Tama Co., Ia. Sec. 2, T83N R16W	Forest	Well	Loess	Gray-Brown Podzolic	Typic Hapludalf	(White, 1953)

Table 2. (Continued)

Soil and profile number	Location	Native vegetation	Natural drainage class	Parent material	Great soil group	7th Approximation classification[a]	Reference
Stronghurst P609	Tama Co., Ia. Sec. 17, T83N R15W	Forest	Somewhat poorly	Loess	Gray-Brown Podzolic	Aeric Ochraqualf	(Corliss, 1958)
Traer P422	Tama Co., Ia. Sec. 18, T83N R15W	Forest	Poorly	Loess	Humic-Gley	Typic Ochraqualf	(Cain, 1956)
Kenyon P701 (14125-14137)[b]	Bremer Co., Ia. Sec. 6, T93N R13W	Prairie	Well	Surficial sediments/till	Brunizem	Typic Hapludoll	(U.S. Soil Survey Staff, 1966)
Readlyn P702 (14116-14124)[b]	Bremer Co., Ia. Sec. 34, T91N R11W	Prairie	Somewhat poorly	Surficial sediments/till	Brunizem	Aquic Hapludoll	(U.S. Soil Survey Staff, 1966)
Tripoli P633	Bremer Co., Ia. Sec. 15, T92N R12W	Prairie	Poorly	Surficial sediments/till	Humic-Gley	Typic Haplaquoll	(Phillips, 1958)
Russell (Ill.) (18825-18833)	Piatt Co., Ill. (not available)	Forest	Well	Loess/till	Gray-Brown Podzolic	Typic Hapludalf	(Bailey *et al.*, 1964)
Toronto (18834-18842)	Piatt Co., Ill. (not available)	Prairie/forest	Somewhat poorly	Loess/till	Brunizem—Gray-Brown Podzolic	Aquollic Hapludalf	(Bailey *et al.*, 1964)

Table 2. (Continued)

Soil and profile number	Location	Native vegetation	Natural drainage class	Parent material	Great soil group	7th Approximation classification[a]	Reference
Toronto (18852-18859)	Champaign Co., Ill. Sec. 1, T19N R9E	Prairie/forest	Somewhat poorly	Loess/till	Brunizem—Gray-Brown Podzolic	Aquollic Hapludalf	(Bailey *et al.*, 1964)
Xenia (18843-18851)	Champaign Co., Ill. (not available)	Forest	Somewhat poorly	Loess/till	Gray-Brown Podzolic	Typic Hapludalf	(Bailey, *et al.*, 1964)
Russell (Ohio) WA37 (10124-10131)	Warren Co., Ohio Sec. 24, T4N R3W	Forest	Well	Loess/till	Gray-Brown Podzolic	Typic Hapludalf	(Ohio Agric. Expt. Sta., 1958)
Fincastle PB-10 (7129-7138)	Preble Co., Ohio Sec. 3 T5N R1E	Forest	Somewhat poorly	Loess/till	Gray-Brown Podzolic	Typic Hapludalf	(Ohio Agric. Expt. Sta., 1958)
Deep till (Till I)	Linn Co., Ia. Sec. 33, T83N R6W			Unoxidized, unleached till			--[d]
Deep till (Till II)	Linn Co., Ia. Sec. 28, T83N R6W			Unoxidized, unleached till			--[d]

no. 481), P737 (Unnamed soil no. 282), P738 (Unnamed soil no. 191), P736 (Unnamed soil no. 282F), Till I and Till II. Duplicate profiles of the same series will be referred to by Roman numeral I and II.

Duplicate cores of the profiles sampled for this investigation were collected with a Giddings hydraulic probe to depths ranging from 60 to 184 inches. The soils were described using standard soil survey procedures as outlined in the Soil Survey Manual (U.S. Soil Survey Staff, 1951), and these descriptions are included in Appendix A. Some of the thicker horizons were subdivided for sampling so that no samples from within the solum would be more than 8 to 10 inches thick. In preparation for the laboratory work the samples were air-dried, crushed to pass a 2 mm sieve and stored in glass jars. The samples from other studies had been prepared in a similar manner.

Laboratory Methods of Analysis

Particle size analysis

Particle size distribution analyses were made on all soils collected for this study. The pipette method described by Kilmer and Alexander (1949) was used. Time intervals for pipetting were determined according to Stokes' Law as calculated by Tanner and Jackson (1947).

Soil reaction

The soil reaction (pH) was determined on all samples collected for this study on a 1:1 soil water suspension using a Sargent glass electrode pH meter.

Dispersion and collection of the <1μ clay fraction

This method is patterned after Protz (1965), but changes were made, and the procedure used is as follows: An 8 gram sample of air-dry soil, crushed to pass a 2 mm sieve, is weighed on a torsion balance and placed in 16 ounce, wide mouth, straight sided jars. Then add 75 ml of neutral, 1 N $LiNO_3$ and allow the suspension to stand for 12 hours. This removes the exchangeable ions from the exchange complex of the soils and saturates the complex with Li^+. The suspension is then filtered through Whatman No. 50 filter paper on a Büchner funnel system with suction. After all the liquid has been removed, add 50 ml of the neutral 1N $LiNO_3$ to insure complete saturation. After this has been removed, wash with two 50 ml aliquots of deionized water. By this time the excess salt is removed and the soil is so dispersed that very little water will pass through it. Fill the funnel with water, and allow it to remain on suction for at least 20 hours. Then transfer soil and filter paper back to the 16 ounce wide mouth jars, bring the liquid to approximately half full with deionized water, shake to loosen soil from filter paper and remove filter paper while washing remaining soil from it with deionized water from a wash bottle. Put the jars on the reciprocating shaker and allow to shake 12 hours. Then remove, make to volume of 400 ml. with deionized water which makes a 2 percent soil suspension. Shake the jars by hand for one minute at one minute intervals, set up single file and loosen the lids. Calculate the settling time for the <1μ clay fraction at the 4 cm. depth according to Stokes' Law as described by Tanner and Jackson (1947). At the prescribed time pipette 15 ml., using a pipette with suction bulb on a ring stand, and put the clay into weighed 35 ml. platinum crucibles. Oven dry at 110° C for at least 16 hours, cool in a dessicator and weigh.

Decomposition of the <1μ clay fraction

The clay is then digested in the platinum crucible according to the HF and $HClO_4$ method described by Jackson (1958 and 1964). However, the sample is held at approximately 170° C until all of the liquid has evaporated to avoid spattering and then is heated to 220° C. The residue is dissolved in 5 ml. of 6 N HCl and 5 to 10 ml. of deionized water from a wash bottle to mix and aid in dissolution of the material. A little heat may be necessary for complete dissolution. The extract is then filtered through Whatman No. 42 filter paper into 50 ml. volumetric flasks, made to volume with deionized water and stored in 2 ounce polyethylene bottles. This solution will be referred to as the "extract solution".

Determination of nonexchangeable potassium

For the determination of nonexchangeable potassium 10 ml. of the extract solution are diluted with deionized water to 50 ml. in volumetric flasks. The expected range of potassium in these dilutions is 1 to 10 ppm, so standards are prepared from KCl in this range and used to make a standard curve. The potassium concentrations were determined on a Coleman, Model 21 flame photometer which does not use an internal standard.

Determination of nonexchangeable magnesium

For the determination of nonexchangeable magnesium 10 ml. of the extract solution plus 5 ml. of a 40,000 ppm strontium solution are diluted with deionized water to 50 ml. in volumetric flasks. The dilution then contains from 1 to 8 ppm magnesium and 4,000 ppm strontium. The strontium minimizes interference from other ions as discussed by Protz (1965). Standards are prepared which include the 4,000 ppm strontium and a standard curve is made. The magnesium concentrations were determined on a Perkin-Elmer, Model 214 Atomic Absorption Spectrophotometer as outlined by Protz (1965).

Determination of exchangeable magnesium and calcium

A 5.000 gram sample of air dry, whole soil crushed to pass a 2 mm. sieve and corrected for moisture content is extracted with neutral 1 N NH_4OAc according to method No. 18 of U.S.D.A. Handbook No. 60 (1954). Then 10 ml. of this exchangeable cation extract plus 5 ml. of 40,000 ppm strontium are used on the atomic absorption spectrophotometer to determine magnesium. The exchangeable cation extract was analyzed for exchangeable calcium according to the procedure of Protz (1965). A 45 ml. aliquot of the exchangeable cation extract plus 5 ml. of the 40,000 ppm strontium solution were mixed and analyzed on the atomic absorption spectrophotometer. Calcium standards with 50, 100, 200, 500 and 1000 ppm calcium in the presence of 4,000 ppm strontium are used to set up the standard curve.

Sodium tetraphenylboron extractable potassium

The method for determining sodium tetraphenylboron (Na TPB) extractable potassium is described by Scott and Reed (1962b) and Smith and Scott (1966) with minor modifications. A 5.000 gram of air-dry (corrected for moisture content) whole soil, crushed to pass a 2 mm. sieve is placed in a 500 ml. erlenmeyer flask with 1.54 g. Na TPB and 15 ml. of a solution which is 1.2 N NaCl and 0.01 M EDTA (disodium-dihydrogen type). Then swirl to mix sample with solution; place in a constant temperature room (about 25° C) and allow to incubate the desired period of time. At the end of the incubation period add 100 ml. 2.3 N NH_4Cl, 200 ml. deionized water and 45 ml. 2 N $HgCl_2$ (under hood) and boil slowly (under hood), for 20 minutes. Allow to cool for 2 to 3 hours and filter through Whatman number 50 paper with gentle suction on a Büchner system. Wash with a small aliquot of NH_4Cl to insure complete collection of K into the filtrate. Transfer the filtrate to 500 ml. volumetric flasks; make to volume with 0.5 N NH_4Cl, and determine the K concentration flame photometrically.

To determine the K concentration, dilute the above extract so that the expected range of K is approximately 1 to 10 ppm; this is usually 5 ml. extract diluted to 25 or 50 ml. The K concentrations in the solution were determined on a Perkin-Elmer flame photometer which uses a 100 ppm Li^+ concentration in the sample as an internal standard.

X-ray diffraction

X-ray diffraction techniques were used to identify the clay minerals and determine the relative intensities (peak areas) in representative profiles and selected samples from other profiles. The <1μ clay fraction was collected as for K and Mg determination according to the procedure described on page 38 in the paragraph entitled "Dispersion and collection of the <1μ clay fraction". The clay is Li^{+} saturated and has not had the organic matter or carbonates removed. The clay suspension is placed on an unglazed ceramic slide and suction is applied to the bottom. The suction removes the water, and the clay forms a thin film on the slide. An attempt should be made to obtain a clay film of approximately the same thickness on all slides. The slides are allowed to air dry. They are glycolated according to the method described by Kunze (1955) by suspending them upside down above the ethylene glycol in a covered dish and placing them in an oven (110^{o} C) for several hours. When the slides appear moist they are removed from the oven and placed in a dessicator containing ethylene glycol instead of a dessicant and are allowed to reach equilibrium with the ethylene glycol atmosphere (about 24 hours) before being x-rayed.

For this study the samples were x-rayed with a General Electric, Model XRD-7 diffractometer, using a copper tube and nickel filter at 35 kilovolts and 45 milliamperes. All patterns were run at 5000 counts per second, but if the peaks were too small or irregular at this setting, additional patterns were run at 2000 counts per second to substantiate the others. The chart speed and scan rate were the same for all samples x-rayed. Identification was made according to the techniques of Bradley and Grim (1961), Brindley (1961), Johns <u>et al</u>. (1954), MacEwan (1961) and Warshaw and Roy (1961). Peaks at 17Å and 10Å were taken to represent the presence of montmorillonite and illite, respectively, in glycolated samples. The presence of a peak at 7.2Å which disappears on heating to 500° C, but does not disappear with dilute HCl treatment, was taken to represent the kaolinitic minerals. Measurable amounts of other clay minerals were not detected. The relative intensities (peak area measurements) were determined by counting the number of 0.01 inch squares under each peak at the 5000 counts per second setting. This does not give a quantitative estimate of the mineral present, but only a comparison between samples.

RESULTS

Laboratory analyses including particle size distribution, nonexchangeable potassium and magnesium, exchangeable potassium and magnesium, sodium tetraphenylboron extractable potassium and x-ray diffraction were made. The data will be presented and discussed in the above order, and the primary emphasis will be on the thin loess/till soils of Iowa. Profiles of the same series sampled at two locations will be referred to by Roman numerals, for example Dinsdale I and Dinsdale II (see Table 2).

Particle Size Distribution

Particle size analysis data including sand, coarse silt, fine silt and clay of the soils sampled for this study are given in Table 3. Clay contents of all the soils analyzed for nonexchangeable potassium and magnesium are given in Table 5. The depths to the middle of the horizon with maximum clay content and the B/A horizon clay ratios of all the profiles studied are given in Table 4.

These soils have a two story profile of approximately 30 inches of loess over glacial till. Most of the profiles do not appear to have any interruption in the leaching processes at the loess-till contact based on the uniform clay distribution curve. The loess portion has a low sand content and a high silt content, and the till portion is just the reverse. In some profiles there is a thin, low clay content layer between the loess and till (sample numbers P733-5 and P734-6), and most profiles have a layer of coarser rock fragments of various concentrations,

Table 3. Particle size analysis and pH of Maxfield (P733 and P734), Waubeek (P732 and P735), Franklin (P730 and P731), P739 (Unnamed soil no. 481), P737 (Unnamed soil no. 282), P738 (Unnamed soil no. 191), P736 (Unnamed soil no. 282F), Till I and Till II

			Particle size (Mm) (Percent)				
Sample number	Horizon	Depth (inches)	2.0-0.05	0.05-0.02	0.02-0.002	<0.002	pH
			Maxfield (P733)				
P733-1	A1p	0- 8	7.1	30.84	31.16	31.0	7.1
2	A12	8- 17	4.7	23.79	35.68	35.8	6.6
3	A3	17- 24	3.4	28.08	33.96	34.6	6.7
4	B2g	24- 34	7.5	32.91	32.68	26.9	7.0
5	IIB31	34- 37	70.1	9.17	8.40	12.4	7.4
6	IIB32	37- 48	57.2	10.6	13.84	18.4	7.9
7	IIC1	48- 64	51.0	14.3	16.96	17.7	8.1
8	IIC2	64- 80	55.5	12.97	15.24	16.3	8.2
9	IIC2	80- 97	55.3	12.67	15.60	16.5	8.2
10	IIC3	97-106	40.1	14.6	22.2	23.1	8.1
			Maxfield (P734)				
P734-1	A1p	0- 7	11.5	23.4	32.2	32.9	6.8
2	A12	7- 13	12.7	24.3	30.0	33.0	6.9
3	A13	13- 20	18.2	22.9	25.6	33.3	7.1
4	A3	20- 25	24.3	19.2	24.3	32.2	7.1
5	B2g	25- 33	34.1	17.6	21.0	27.3	7.6
6	IIB31	33- 38	59.1	12.6	12.3	16.0	7.7
7	IIB32	38- 48	56.7	7.6	14.4	21.3	8.2
8	IIC1	48- 62	44.8	14.0	17.2	25.0	8.1
9	IIC2	62- 74	44.4	13.2	19.2	23.2	8.2
10	IIC2	74- 86	44.9	5.5	24.8	24.8	8.2
11	IIC2	86-101	43.7	13.6	19.0	23.7	8.3
12	IIC3	101-117	42.6	13.6	18.3	25.5	8.3
13	IIC4	117-125	42.6	14.7	17.4	25.3	8.3
14	IIC5	125-131	40.8	14.9	18.7	25.6	8.3
15	IIC6	131-148	41.0	14.7	19.0	25.3	8.2
16	IIC6	148-172	41.2	14.5	19.0	25.3	8.1
17	IIC7	172-184	39.8	15.0	19.0	26.3	8.1
			Waubeek (P732)				
P732-1	A1p	0- 7	4.8	37.36	36.44	21.4	7.2
2	A2	7- 9½	3.4	33.97	35.40	27.2	6.8
3	B1	9½-14	3.4	31.04	33.12	32.5	6.1
4	B21	14- 23	4.2	30.16	30.48	35.1	5.3
5	B22	23- 31	22.6	25.22	23.32	28.8	5.2

Table 3. (Continued)

Sample number	Horizon	Depth (inches)	Particle size (Mm) (Percent) 2.0-0.05	0.05-0.02	0.02-0.002	<0.002	pH
			Waubeek (P732) (continued)				
P732-6	IIB23	31- 41	47.0	13.53	14.32	25.2	5.2
7	IIB3	41- 55	49.2	11.16	14.44	25.2	5.9
8	IIC1	55- 72	52.0	11.11	14.08	22.8	7.0
9	IIC2	72- 85	51.5	13.02	15.12	20.4	7.9
10	IIC2	85- 98	52.7	11.58	15.08	20.6	7.9
11	IIC3	98-122	53.7	11.20	17.10	18.0	8.1
			Waubeek (P735)				
P735-1	A1p	0- 6	5.6	37.3	37.9	19.2	7.1
2	A21	6- 9	5.8	35.6	38.2	19.4	6.9
3	A22	9- 14	4.6	33.3	37.2	24.9	6.4
4	B1	14- 21	5.6	34.2	32.2	27.8	5.5
5	B21	21- 28	7.7	32.6	30.4	29.3	5.0
6	B22	28- 32	14.2	30.5	25.7	29.6	5.0
7	IIB23	32- 38	44.7	14.8	15.5	25.0	5.1
8	IIB31	38- 44	46.3	12.2	14.7	26.8	5.1
9	IIB32	44- 54	44.5	12.6	15.8	27.1	5.5
10	IIC1	54- 67	44.2	12.6	16.2	27.0	6.2
11	IIC2	67- 81	43.5	12.8	16.0	27.7	7.2
12	IIC3	81- 92	41.8	15.0	19.6	23.6	8.3
13	IIC3	92-104	40.4	14.0	17.9	27.7	8.1
			Franklin (P730)				
P730-1	A1p	0- 6	8.4	33.30	33.6	24.7	6.8
2	A12	6- 9	8.1	33.42	33.12	25.4	6.8
3	A2	9- 16	6.3	50.25	15.26	28.2	5.5
4	B1	16- 22	6.6	1.50	59.84	32.0	5.1
5	B21	22- 32	13.8	33.06	21.72	31.4	5.3
6	IIB22	32- 42	47.1	14.63	15.52	22.7	5.6
7	IIB3	42- 49	46.5	13.03	18.32	22.1	6.1
8	IIC1	49- 68	47.5	15.27	16.48	20.7	6.8
9	IIC2	68- 90	51.8	15.84	15.96	16.4	8.0
10	IIC3	90-110	53.8	15.87	15.04	15.2	8.1
			Franklin (P731)				
P731-1	A1p	0- 8	5.4	39.65	36.56	18.4	7.3
2	A21	8- 12	3.3	32.73	36.76	27.2	5.7
3	B1	12- 16	2.7	30.19	33.00	34.1	5.0
4	B21	16- 23	3.0	29.70	32.52	34.8	5.0

Table 3. (Continued)

Sample number	Horizon	Depth (inches)	Particle size (Mm) (Percent) 2.0-0.05	0.05-0.02	0.02-0.002	<0.002	pH
			Franklin (P731) (continued)				
P731-5	B22	23- 29	3.6	32.22	31.64	33.4	5.1
6	B23	29- 34	8.1	32.22	26.40	33.3	5.2
7	IIB31	34- 46	47.7	14.66	13.96	23.7	6.5
8	IIB32	46- 62	48.3	15.00	13.46	23.2	6.9
9	IIC1	62- 80	49.2	12.80	13.60	24.4	7.3
10	IIC2	80- 96	42.3	22.49	14.84	20.4	8.1
11	IIC2	96-112	40.9	22.94	15.88	20.3	8.1
			P739 (Unnamed soil no. 481)				
P739-1	A1	0- 5	7.0	34.2	36.0	22.8	5.6
2	A21	5- 9	9.5	34.4	35.0	21.1	5.4
3	A22	9- 13	8.7	32.4	34.4	24.5	5.1
4	B1	13- 20	6.9	29.6	33.9	29.6	4.7
5	B21	20- 26	8.2	18.8	30.8	32.2	4.5
6	B22	26- 33	11.9	27.0	29.2	31.9	4.5
7	IIB23	33- 39	46.4	11.4	16.2	26.0	4.7
8	IIB3	39- 47	50.0	8.7	15.9	25.4	4.5
9	IIC1	47- 57	49.1	9.5	16.1	25.3	5.0
10	IIC2	57- 68	50.3	9.1	16.6	24.0	5.7
11	IIC3	68- 79	49.9	9.4	17.1	23.6	6.9
12	IIC3	79- 90	49.8	9.9	16.5	23.8	7.1
13	IIC4	90-105	50.0	9.7	17.0	23.3	7.8
14	IIC4	105-120	51.2	9.8	16.2	22.8	8.0
			P737 (Unnamed soil no. 282)				
P737-1	Alp	0- 7	8.4	29.3	28.3	34.0	5.7
2	A12	7- 14	7.7	30.6	26.9	34.8	6.7
3	A3	14- 20	7.1	30.9	27.3	34.7	7.0
4	B1	20- 27	7.7	31.8	27.9	32.6	7.3
5	B2	27-32	12.8	32.2	30.0	25.0	7.8
6	IIC1	32- 40	32.0	17.0	24.0	27.0	8.0
7	IIC2	40- 49	32.5	15.1	24.8	27.6	8.1
8	IIC3	49- 60	30.6	15.2	25.7	28.4	8.1
			P738 (Unnamed soil no. 191)				
P738-1	Alp	0- 7	6.3	29.1	27.5	37.1	6.7
2	A12	7- 14	5.1	18.0	28.5	39.4	6.7
3	A3	14- 20	5.4	24.4	30.2	40.0	6.8
4	B1	20- 25	7.4	24.9	28.5	39.2	7.2

Table 3. (Continued)

Sample number	Horizon	Depth (inches)	Particle size (Mm) (Percent) 2.0-0.05	0.05-0.02	0.02-0.002	<0.002	pH
		P738 (Unnamed soil no. 191) (continued)					
P738-5	B29	25- 32	9.9	25.3	28.1	36.7	7.4
6	IIB3	32- 38	28.2	16.9	24.9	30.0	8.1
7	IIC1	38- 45	26.6	14.0	26.8	32.6	8.3
8	IIC2	45- 52	29.2	13.6	26.6	30.6	8.3
9	IIC2	52- 60	28.5	15.4	26.6	29.5	8.3
		P736 (Unnamed soil no. 282F)					
P736-1	A1	0- 6	5.4	34.0	36.0	24.6	5.1
2	A21	6- 11	6.1	31.1	39.8	23.0	5.3
3	A22	11- 19	4.9	24.5	36.2	34.4	5.2
4	B1	19- 24	5.5	23.6	29.9	41.0	5.0
5	B21	24- 30	11.9	22.4	27.0	38.7	5.3
6	IIB22	30- 35	28.3	14.7	19.4	37.6	5.5
7	IIB23	35- 39	26.9	14.2	21.1	37.8	6.3
8	IIC1	39- 47	28.7	13.9	26.3	31.1	7.8
9	IIC2	47- 54	30.6	14.3	27.5	27.6	7.9
10	IIC2	54- 60	30.0	14.6	27.2	28.2	7.9
			Till I				
Till I-1	DU[a]	30[b]	46.3	23.7	18.3	21.7	8.3
2	UU[c]	40[b]	40.0	13.9	22.0	24.1	8.1
3	UU	50[b]	40.5	14.1	23.5	21.9	8.2
4	UU	100[b]	39.0	20.3	28.5	12.2	8.1
			Till II				
Till II-1	OL[d]	5[b]	46.8	10.9	16.3	26.0	7.3
2	UU	20[b]	49.3	11.3	18.0	21.4	8.1
3	UU	30[b]	48.3	11.7	19.6	20.4	8.1

[a]DU = deoxidized, unleached till.
[b]Feet below surface, approximately.
[c]UU = unoxidized, unleached till.
[d]OL = oxidized, leached till.

Table 4. The B/A horizon clay ratio, depth to maximum clay and related data for horizons with maximum clay accumulation of the soils studied

Sample number	Depth (inches)	Horizon of max. clay	Native veg.[a]	B/A horizon clay ratio	Depth to max. clay	Geog. location	Ave. annual rainfall	Ions in horizon of max. clay % Mg	% K
P704-4	15-21	B1	P	1.14	15	E. Ia.	33	1.02	1.28
P705-3	12-16	B1	P	1.14	14	E. Ia.	33	.98	1.33
P706-3	13-18	A3	P	1.08	16	E. Ia.	33	1.17	1.37
P707-3	13-19	B1	P	1.08	16	E. Ia.	33	.91	1.33
P733-2	8-17	A12	P	1.15	12	E. Ia.	33	.93	1.26
P734-3	13-20	A13	P	1.01	16	E. Ia.	33	.98	1.21
P732-4	14-23	B21	P/F	1.64	19	E. Ia.	33	.92	1.01
P735-5	21-28	B21	P/F	1.53	24	E. Ia.	33	1.05	1.37
P730-4	16-22	B1	P/F	1.30	19	E. Ia.	33	.88	1.15
P731-4	16-23	B21	P/F	1.89	19	E. Ia.	33	1.16	1.23
P739-5	20-26	B21	F	1.41	23	E. Ia.	33	1.01	1.38
P746-2	7-11	A3	P	1.02	9	N.W. Ia.	27	1.05	1.59
P747-2	8-13	A3	P	1.03	10	N.W. Ia.	27	1.11	1.56
P737-2	7-14	A12	P	1.02	10	N.W. Ia.	27	1.20	1.48
P738-3	14-20	A3	P	1.08	17	N.W. Ia.	27	1.17	1.58
P736-4	19-24	B1	P/F	1.67	21	N.W. Ia.	27	.95	1.14
Pa1-1-5	21-25	B21	P	1.16	23	E. Ia.	33	1.19	1.21
P94-7	18-21	B1	P	1.14	20	E. Ia.	33	1.04	1.38

[a]P = prairie, P/F = prairie/forest transition and F = forest vegetation.

Table 4. (Continued)

Sample number	Depth (inches)	Horizon of max. clay	Native veg.[a]	B/A horizon clay ratio	Depth to max. clay	Geog. location	Ave. annual rainfall	Ions in horizon of max. clay % Mg	% K
Pa1-3-3	12-18	A3	P	1.10	15	E. Ia.	33	1.13	1.22
P428-7	18-22	B21	P/F	1.54	20	E. Ia.	33	.91	1.22
P608-8	29-35	B2	P/F	1.68	32	E. Ia.	33	1.09	1.21
P607-7	18-22	B22	P/F	2.16	20	E. Ia.	33	.93	1.10
P32-9	22-25	B22	F	1.50	24	E. Ia.	33	.98	1.34
P609-6	18-22	B2	F	2.26	20	E. Ia.	33	.95	1.26
P422-5	19-23	B2	F	2.15	21	E. Ia.	33	1.05	1.23
P701-6	24-30	IIB22	P	1.56[b]	27	E. Ia.	33	.87	1.56
P702-4	17-24	IIB21	P	1.24[b]	21	E. Ia.	33	.93	1.16
P633-4	15-19	B1g	P	1.10[b]	17	E. Ia.	33	.79	1.00
18829	17-25	B21	F	2.18	21	E. Ill.	38	1.20	1.52
18838	21-28	B21	P/F	1.87	26	E. Ill.	38	.77	.89
18856	22-29	B21	P/F	1.43	26	E. Ill.	38	1.17	1.52
18847	18-28	B21	P/F	1.64	23	E. Ill.	38	1.13	1.62
10128	25-32	IIB3	F	1.91	29	S.W. Ohio	40	1.18	3.04
7132	14-19	B21	P/F	2.42	17	S.W. Ohio	40	.58	1.09

[b]The B/A horizon clay ratios for the soils of the Kenyon sequence are unreal because the B horizon is in till which has a higher original clay content than the A horizon. The values should be approximately 1.0.

Table 5. Nonexchangeable potassium and related data for the soils studied

Sample number	Depth (inches)	Horizon	<2μ clay %	Nonexch. K in <1μ fraction %	Exch. K+ in whole soil me/ 100g	%K x %<2μ clay	%K/% <2μ clay ratio	%K/ me/ 100g K+ ratio
				Sac (P746)				
P746-1	0- 7	A1p	37.5[a]	1.73	0.8[a]	64.9	0.05	2.1
2	7- 11	A3	38.4	1.59	0.5	61.1	0.04	3.2
3	11- 18	B1	37.4	1.43	0.4	53.5	0.04	3.6
4	18- 25	B21	33.6	1.57	0.4	52.8	0.05	3.9
5	25- 28	IIB22	31.7	1.61	0.4	51.0	0.05	4.0
6	28- 33	IIB23	32.0	1.71	0.3	54.7	0.05	5.7
7	33- 44	IIB3ca	33.7	2.00	0.3	67.4	0.06	6.7
8	44- 57	IICca	34.4	1.95	0.3	67.1	0.06	6.5
				Sac (P747)				
P747-1	0- 8	A1p	36.8[a]	1.66	0.6[a]	61.1	0.05	2.8
2	8- 13	A3	38.2	1.56	0.4	59.6	0.04	3.9
3	13- 18	B1	36.8	1.54	0.4	56.7	0.04	4.1
4	18- 25	B21	34.0	1.55	0.4	52.7	0.05	3.9
5	25- 28	IIB22	31.7	1.64	0.3	52.0	0.05	5.5
6	28- 33	IIB23	35.5	1.87	0.3	66.4	0.05	6.2
7	33- 47	IIB3ca	28.2	1.97	0.2	55.6	0.06	9.9
8	47- 60	IICca	25.6	2.03	0.2	52.0	0.08	10.2
				P737 (Unnamed soil no. 282)				
P737-1	0- 7	A1p	34.0	1.45		47.6	0.04	
2	7- 14	A12	34.8	1.48		51.5	0.04	
3	14- 20	A3	34.7	1.44		50.0	0.04	
4	20- 27	B1	32.6	1.42		46.3	0.04	
5	27- 32	B2	25.0	1.41		35.3	0.05	
6	32- 40	IIC1	27.0	1.99		53.7	0.07	
7	40- 49	IIC2	27.6	1.94		53.5	0.07	
8	49- 60	IIC3	28.4	2.20		62.5	0.08	
				P738 (Unnamed soil no. 191)				
P738-1	0- 7	A1p	37.1	1.56		57.9	0.04	
2	7- 14	A12	39.4	1.40		55.2	0.04	
3	14- 20	A3	40.0	1.58		63.2	0.04	
4	20- 25	B1	39.2	1.34		52.5	0.03	
5	25- 32	B2g	36.7	1.21		44.4	0.03	

[a]Data from Lincoln Soil Survey Laboratory (U.S. Soil Survey Staff,1966)

Table 5. (Continued)

Sample number	Depth (inches)	Horizon	<2μ clay %	Nonexch. K in <1μ fraction %	Exch. K+ in whole soil me/ 100g	%K x %<2μ clay	%K/% <2μ clay ratio	%K/ me/ 100g K+ ratio
			P738 (Unnamed soil no. 191) (continued)					
P738-6	32- 38	IIB3	30.0	1.80		54.0	0.06	
7	38- 45	IIC1	32.6	1.68		54.8	0.05	
8	45- 52	IIC2	30.6	1.62		49.6	0.05	
9	52- 60	IIC2	29.5	1.38		40.7	0.05	
			P736 (Unnamed soil no. 282F)					
P736-1	0- 6	A1	24.6	1.51		37.2	0.06	
2	6- 11	A21	23.0	1.74		40.0	0.08	
3	11- 19	A22	34.4	1.42		48.9	0.04	
4	19- 24	B1	41.0	1.14		46.7	0.03	
5	24- 30	B21	38.7	1.18		45.7	0.03	
6	30- 35	IIB22	37.6	1.13		41.4	0.03	
7	35- 39	IIB23	37.8	1.31		49.5	0.03	
8	39- 47	IIC1	31.1	1.48		46.0	0.05	
9	47- 54	IIC2	27.6	1.70		46.9	0.06	
10	54- 60	IIC2	28.2	1.87		52.7	0.07	
			Dinsdale (P704)					
P704-1	0- 7	A1p	28.8[a]	1.57	0.3[a]	50.2	0.06	5.2
2	7- 11	A12	31.2	1.43	0.3	44.6	0.05	4.8
3	11- 15	A3	32.7	1.35	0.4	44.2	0.04	3.4
4	15- 21	B1	32.9	1.28	0.4	42.1	0.04	3.2
5	21- 29	B2	31.7	1.29	0.4	40.9	0.04	3.2
6	29- 36	B31	29.7	1.43	0.4	42.5	0.05	3.6
7	36- 43	IIB32	23.6	1.77	0.2	41.8	0.08	8.9
8	43- 50	IIB33	21.7	1.94	0.2	42.1	0.09	9.7
9	50- 56	IIC1	23.1	1.95	0.2	45.1	0.02	9.8
10	56- 62	IIC2	19.5	2.19	0.2	42.7	0.11	11.0
11	62-73	IIC3	18.7	2.08	0.2	38.9	0.11	10.4
			Dinsdale (P705)					
P705-1	0- 6	A1p	29.2[a]	1.73	0.4[a]	50.5	0.06	4.3
2	6- 12	A3	33.1	1.48	0.4	49.0	0.04	3.7
3	12- 16	B1	33.4	1.33	0.4	44.4	0.04	3.3
4	16- 21	B21	32.9	1.24	0.5	40.8	0.04	2.5
5	21- 26	B22	29.2	1.48	0.4	43.2	0.05	3.7
6	26- 30	B23	23.9	1.74	0.3	41.6	0.07	5.8

Table 5. (Continued)

Sample number	Depth (inches)	Horizon	<2μ clay %	Nonexch. K in <1μ fraction %	Exch. K+ in whole soil me/100g	%K x %<2μ clay	%K/%<2μ clay ratio	%K/me/100g K+ ratio
			Dinsdale (P705) (continued)					
P705-7	30- 37	IIB31	22.3	2.09	0.3	46.6	0.09	7.0
8	37- 44	IIB32	25.2	2.26	0.3	56.9	0.09	7.5
9	44- 48	IIB33	22.7	2.36	0.3	53.6	0.10	7.9
10	48- 58	IIC1	21.0	2.44	0.2	51.2	0.12	12.2
11	58- 66	IIC2	20.8	2.37	0.2	49.3	0.11	11.9
			Klinger (P706)					
P706-1	0- 7	A1p	27.5[a]	1.37	0.2[a]	37.7	0.07	6.9
2	7- 13	A12	29.2	1.44	0.3	42.1	0.05	4.8
3	13- 18	A3	29.8	1.37	0.4	40.8	0.05	3.4
4	18- 23	B1	29.8	1.30	0.4	38.7	0.04	3.3
5	23- 28	B21	24.2	1.41	0.4	34.1	0.06	3.5
6	28- 33	B22	21.1	1.91	0.3	40.3	0.09	6.4
7	33- 40	IIB3	20.1	1.82	0.2	36.6	0.09	9.1
8	40- 50	IIC1	19.6	1.81	0.2	35.5	0.09	9.1
9	50- 68	IIC2	19.9	1.94	0.2	38.6	0.10	9.7
			Klinger (P707)					
P707-1	0- 9	A1	28.9[a]	1.66	0.2[a]	48.0	0.06	8.3
2	9- 13	A3	28.1	1.58	0.3	44.4	0.06	5.3
3	13- 19	B1	31.1	1.33	0.4	41.4	0.04	3.3
4	19- 26	B21	30.6	1.29	0.4	39.5	0.04	3.2
5	26- 31	B22	26.8	1.27	0.4	34.0	0.05	3.2
6	31- 36	IIB31	20.9	1.62	0.2	33.9	0.08	8.1
7	36- 40	IIB32	25.6	1.50	0.2	38.4	0.06	7.5
8	40- 46	IIB33	28.1	1.43	0.2	35.4	0.05	7.2
9	46- 52	IIC1	27.9	1.51	0.2	42.1	0.05	7.6
10	52- 64	IIC2	26.9	1.47	0.2	39.5	0.05	7.4
			Maxfield (P733)					
P733-1	0- 8	A1p	31.0	1.18		36.6	0.04	
2	8- 17	A12	35.8	1.26		45.1	0.04	
3	17- 24	A3	34.6	1.20		41.5	0.04	
4	24- 34	B B2g	26.9	1.34		36.1	0.05	
5	34- 37	IIB31	12.4	1.58		19.6	0.13	
6	37- 48	IIB32	18.4	1.68		30.9	0.09	

Table 5. (Continued)

Sample number	Depth (inches)	Horizon	<2μ clay %	Nonexch. K in <1μ fraction %	Exch. K+ in whole soil me/100g	%K x %<2μ clay	%K/% <2μ clay ratio	%K/ me/ 100g K+ ratio
			Maxfield (P733) (continued)					
P733-7	48- 64	IIC1	17.7	1.82		32.2	0.10	
8	64- 80	IIC2	16.3	1.86		30.3	0.11	
9	80- 97	IIC2	16.5	1.89		31.2	0.12	
10	97-106	IIC3	23.1	1.86		43.0	0.12	
			Maxfield (P734)					
P734-1	0- 7	A1p	32.9	1.14		37.5	0.03	
2	7- 13	A12	33.0	1.15		38.0	0.03	
3	13- 20	A13	33.3	1.21		40.3	0.04	
4	20- 25	A3	32.2	1.24		39.9	0.04	
5	25- 33	B2g	27.3	.99		27.0	0.04	
6	33- 38	IIB31	16.0	1.28		20.5	0.08	
7	38- 48	IIB32	21.3	1.46		31.1	0.07	
8	48- 62	IIC1	25.0	1.69		42.3	0.07	
9	62- 74	IIC2	23.2	1.81		42.0	0.08	
10	74- 86	IIC2	24.8	1.64		40.7	0.07	
11	86-101	IIC2	23.7	1.86		44.1	0.08	
12	101-117	IIC3	25.5	1.55		39.5	0.06	
13	117-125	IIC4	25.3	1.82		46.1	0.07	
14	125-131	IIC5	25.6	1.54		39.4	0.06	
15	131-148	IIC6	25.3	1.59		40.2	0.06	
16	148-172	IIC6	25.3	1.50		38.0	0.06	
17	172-184	IIC7	26.3	1.64		43.1	0.06	
			Waubeek (P732)					
P732-1	0- 7	A1p	21.4	1.87		40.0	0.09	
2	7- 9½	A2	27.2	1.61		43.8	0.06	
3	9½-14	B1	32.5	1.25		40.6	0.04	
4	14- 23	B21	35.1	1.01		35.5	0.03	
5	23- 31	B22	28.8	1.13		32.5	0.04	
6	31- 41	IIB23	25.2	1.27		32.0	0.05	
7	41- 55	IIB3	25.2	1.37		34.5	0.05	
8	55- 72	IIC1	22.8	1.40		31.9	0.06	
9	72- 85	IIC2	20.4	1.74		35.5	0.09	
10	85- 98	IIC2	20.6	1.61		33.2	0.08	
11	98-122	IIC3	18.0	1.79		32.2	0.10	

Table 5. (Continued)

Sample number	Depth (inches)	Horizon	<2μ clay %	Nonexch. K in <1μ fraction %	Exch. K+ in whole soil me/100g	%K x %<2μ clay	%K/% <2μ clay ratio	%K/me/100g K+ ratio
				Waubeek (P735)				
P735-1	0- 6	Alp	19.2	1.73		33.2	0.09	
2	6- 9	A21	19.4	1.84		35.7	0.09	
3	9- 14	A22	24.9	1.60		39.8	0.06	
4	14- 21	B1	27.8	1.47		40.9	0.05	
5	21- 28	B21	29.3	1.37		40.1	0.05	
6	28- 32	B22	29.6	1.34		39.7	0.05	
7	32- 38	IIB23	25.0	1.22		30.5	0.05	
8	38- 44	IIB31	26.8	1.28		34.3	0.05	
9	44- 54	IIB32	27.1	1.45		39.3	0.05	
10	54- 67	IIC1	27.0	1.52		41.0	0.06	
11	67- 81	IIC2	27.7	1.68		46.5	0.06	
12	81- 92	IIC3	23.6	1.66		39.2	0.07	
13	92-104	IIC3	27.7	1.62		44.9	0.06	
				Franklin (P730)				
P730-1	0- 6	Alp	24.7	1.52		37.5	0.06	
2	6- 9	A12	25.4	1.43		36.3	0.06	
3	9- 16	A2	28.2	1.23		34.7	0.04	
4	16- 22	B1	32.0	1.15		36.8	0.04	
5	22- 32	B21	31.4	.94		29.5	0.03	
6	32- 42	IIB22	22.7	1.29		29.3	0.06	
7	42- 49	IIB3	22.1	1.54		34.0	0.07	
8	49- 68	IIC1	20.7	1.28		26.5	0.06	
9	68- 90	IIC2	16.4	1.93		31.7	0.12	
10	90-110	IIC3	15.2	2.16		32.8	0.14	
				Franklin (P731)				
P731-1	0- 8	Alp	18.4	1.63		30.0	0.09	
2	8- 12	A21	27.2	1.21		32.9	0.04	
3	12- 16	B1	34.1	1.12		38.2	0.03	
4	16- 23	B21	34.8	1.23		42.8	0.04	
5	23- 29	B22	33.4	0.97		32.4	0.03	
6	29- 34	B23	33.3	0.84		28.0	0.03	
7	34- 46	IIB31	23.7	0.95		22.5	0.04	
8	46- 62	IIB32	23.2	1.49		34.6	0.06	
9	62- 80	IIC1	24.4	1.46		35.6	0.06	
10	80- 96	IIC2	20.4	1.73		35.3	0.08	
11	96-112	IIC2	20.3	1.84		37.4	0.09	

Table 5. (Continued)

Sample number	Depth (inches)	Horizon	<2μ clay %	Nonexch. K in <1μ fraction %	Exch. K+ in whole soil me/100g	%K x %<2μ clay	%K/%<2μ clay ratio	%K/me/100g K+ ratio
			P739 (Unnamed soil no. 481)					
P739-1	0- 5	A1	22.8	2.02		46.1	0.09	
2	5- 9	A21	21.1	2.13		44.9	0.10	
3	9- 13	A22	24.5	1.92		47.0	0.08	
4	13- 20	B1	29.6	1.55		45.9	0.05	
5	20- 26	B21	32.2	1.38		44.4	0.04	
6	26- 33	B22	31.9	1.39		38.0	0.04	
7	33- 39	IIB23	26.0	1.62		42.1	0.06	
8	39- 47	IIB3	25.4	1.66		42.2	0.07	
9	47- 57	IIC1	25.3	1.70		43.0	0.07	
10	57- 68	IIC2	24.0	1.70		40.8	0.07	
11	68- 79	IIC3	23.6	1.87		44.1	0.08	
12	79- 90	IIC3	23.8	1.97		46.9	0.08	
13	90-105	IIC4	23.3	1.76		41.0	0.08	
14	105-120	IIC4	22.8	1.72		39.2	0.08	
			Tama (Pa1-1)					
Pa1-1-1	0- 7	Ap	29.2[b]	1.63		47.6	0.06	
2	7- 11	A12	31.2	1.53		47.7	0.05	
3	11- 16	A3	32.4	1.41		45.7	0.04	
4	16- 21	B1	33.2	1.27		42.2	0.04	
5	21- 25	B21	33.8	1.21		40.9	0.04	
6	25- 29	B22	33.2	1.23		40.8	0.04	
7	29- 34	B23	31.2	1.26		39.3	0.04	
8	34- 40	B31	29.1	1.30		37.8	0.04	
9	40- 46	B32	27.6	1.39		38.4	0.05	
10	46- 52	C	25.2	1.47		37.0	0.06	
			Muscatine (P-94)					
P94-1	0- 3	A1	31.0[c]	1.66		51.5	0.05	
3	6- 9	A1	33.9	1.72		58.3	0.05	
5	12- 15	A1	34.2	1.58		54.0	0.05	
77	18- 21	B1	35.3	1.38		48.7	0.04	
9	24- 27	B2	35.0	1.33		46.6	0.04	

[b]Data from Fenton (1966).

[c]Data from Corliss (1958).

Table 5. (Continued)

Sample number	Depth (inches)	Horizon	$<2\mu$ clay %	Nonexch. K in $<1\mu$ fraction %	Exch. K+ in whole soil me/ 100g	%K x %$<2\mu$ clay	%K/% $<2\mu$ clay ratio	%K/ me/ 100g K+ ratio
				Muscatine (P-94) (continued)				
P94-11	30- 33	B2	32.7	1.28		41.9	0.04	
13	36- 40	B3	29.7	1.38		41.0	0.05	
15	44- 48	C1	28.8	1.45		41.7	0.05	
17	52- 56	C1	28.5	1.46		41.6	0.05	
19	62- 70	C1	23.7	1.47		34.8	0.06	
				Garwin (Pal-3)				
Pal-3-1	0- 7	Ap	33.3[b]	1.32		44.0	0.04	
2	7- 12	A12	35.5	1.22		43.3	0.03	
3	12- 18	A3	35.6	1.22		43.4	0.03	
4	18- 22	B1	35.3	1.19		42.0	0.03	
5	22- 27	B21g	35.2	1.23		43.3	0.03	
6	27- 31	B22g	32.3	1.26		40.7	0.04	
7	31- 36	B22g	30.8	1.42		43.7	0.05	
8	36- 42	B31g	27.9	1.48		41.3	0.05	
9	42- 48	B32g	23.3	1.47		34.3	0.06	
10	48- 54	C	21.2	1.57		33.3	0.07	
				Downs (P428)				
P428-1	0- 3	A1	23.1[c]	2.00		46.2	0.09	
2	3- 6	A21	23.6	2.03		47.9	0.09	
3	6- 9	A22	24.7	1.96		48.4	0.08	
4	9- 12	A23	26.8	1.90		50.9	0.07	
5	12- 15	A31	30.2	1.58		47.7	0.05	
6	15- 18	B1	31.1	1.42		44.2	0.05	
7	18- 22	B21	35.6	1.22		43.4	0.03	
8	22- 26	B22	34.6	1.23		42.5	0.04	
9	26- 30	B22	33.8	1.27		42.9	0.04	
10	30- 34	B22	31.9	1.32		42.1	0.04	
11	34- 40	B3	31.1	1.30		40.4	0.04	
12	40- 46	C1	30.3	1.30		39.4	0.04	
13	46- 52	C1	30.3	1.28		38.8	0.04	

Table 5. (Continued)

Sample number	Depth (inches)	Horizon	<2μ clay %	Nonexch. K in <1μ fraction %	Exch. K+ in whole soil me/ 100g	%K x %<2μ clay	%K/% <2μ clay ratio	%K/ me/ 100g K+ ratio
				Atterberry (P608)				
P608-1	0- 4	Ap	21.1[c]	2.19		46.2	0.10	
2	4- 7	Ap	21.2	2.02		42.8	0.10	
3	7- 11	A2	23.2	1.84		42.7	0.08	
4	11- 15	A2	24.4	1.92		46.9	0.08	
5	15- 19	A3	26.2	1.77		46.4	0.07	
6	19- 24	B1	32.1	1.37		44.0	0.04	
7	24- 29	B2	35.2	1.34		47.2	0.04	
8	29- 35	B2	35.4	1.21		42.8	0.03	
9	35- 41	B3	31.9	1.25		39.9	0.04	
10	41- 54	B3	31.0	1.33		41.2	0.04	
11	54- 68	C	29.0	1.38		40.0	0.04	
				Walford (P607)				
P607-1	0- 4	Ap	18.9[c]	2.01		38.0	0.11	
2	4- 8	A2	18.5	2.06		38.1	0.11	
3	8- 10	A2	22.7	1.76		40.0	0.08	
4	10- 12	A2	24.8	1.74		43.2	0.07	
5	12- 15	B1	30.0	1.59		47.7	0.05	
6	15- 18	B21	36.8	1.11		40.9	0.03	
7	18- 22	B22	40.9	1.10		45.0	0.03	
8	22- 25	B23	38.9	1.08		42.0	0.03	
9	25- 31	B23	38.1	1.37		52.2	0.04	
10	31- 38	B3	36.8	1.18		43.4	0.03	
11	38- 45	B3	35.1	1.15		40.4	0.03	
12	45- 51	C	32.1	1.29		41.4	0.04	
13	51- 62	C	27.3	1.70		46.4	0.06	
				Fayette (P32)				
P32-3	4- 7	A21	20.6[c]	2.21		45.5	0.11	
5	10- 13	A3	20.5	1.95		40.0	0.10	
7	16- 19	B1	29.7	1.39		41.3	0.05	
9	22- 25	B22	35.5	1.34		47.6	0.04	
11	28- 31	B22	35.3	1.26		44.5	0.04	
13	34- 37	B31	32.3	1.23		39.7	0.04	
15	40- 43	B32	31.5	1.38		43.5	0.04	
17	46- 49	C	29.4	1.41		41.5	0.05	

Table 5. (Continued)

Sample number	Depth (inches)	Horizon	<2μ clay %	Nonexch. K in <1μ fraction %	Exch. K+ in whole soil me/ 100g	%K x %<2μ clay	%K/% <2μ clay ratio	%K/ me/ 100g K+ ratio
			Stronghurst (P609)					
P609-1	0- 4	Ap	17.1[c]	1.66		28.3	0.10	
2	4- 7	A2	17.2	1.87		32.2	0.11	
3	7- 11	A2	21.0	1.80		37.8	0.09	
4	11- 15	A2	27.6	1.58		43.6	0.06	
5	15- 18	B1	33.9	1.34		45.4	0.04	
6	18- 22	B2	38.7	1.26		48.8	0.03	
7	22- 25	B2	38.2	1.11		42.4	0.03	
8	25- 29	B2	36.5	1.09		39.8	0.03	
9	29- 33	B3	35.0	1.21		42.4	0.03	
10	33- 38	B3	32.9	1.27		41.8	0.04	
11	38- 45	B3	31.6	1.33		42.0	0.04	
12	45- 53	C1	30.4	1.42		43.2	0.05	
13	53- 65	C1	31.4	1.34		42.1	0.04	
			Traer (P422)					
P422-1	0- 7	Ap	18.4[c]	1.45		26.7	0.08	
2	7- 10	A2	23.8	1.59		37.8	0.07	
3	10- 13	B1	30.9	1.38		42.6	0.04	
4	13- 19	B2	38.7	1.42		55.0	0.04	
5	19- 23	B2	39.5	1.23		48.6	0.03	
6	23- 29	B3	35.9	1.25		44.9	0.03	
7	29- 35	C1	34.4	1.22		42.0	0.04	
8	35- 41	C1	33.4	1.26		42.1	0.04	
9	41- 50	Cca	29.1	1.41		41.0	0.05	
10	50- 55	Cca	24.1	1.44		34.7	0.06	
			Kenyon (P701)					
P701-1	0- 5	A1p1	18.4[a]	1.48	0.2[a]	27.2	0.08	7.4
2	5- 9	A1p2	24.4	1.39	0.2	33.9	0.06	6.9
3	9- 13	A3	24.6	1.38	0.2	33.9	0.06	6.9
4	13- 18	IIB1	24.5	1.44	0.2	35.3	0.06	7.2
5	18- 24	IIB2	28.5	1.53	0.2	43.6	0.05	7.7
6	24- 30	IIB22	28.8	1.56	0.2	44.9	0.05	7.8
7	30- 37	IIB23	28.5	1.71	0.2	48.7	0.06	8.6
8	37- 45	IIB31	27.4	1.77	0.2	48.5	0.06	8.7
9	45- 55	IIB32	27.3	1.77	0.2	48.3	0.06	8.7
10	55- 65	IIC1	25.2	1.96	0.2	49.4	0.08	9.8

Table 5. (Continued)

Sample number	Depth (inches)	Horizon	<2µ clay %	Nonexch. K in <1µ fraction %	Exch. K+ in whole soil me/100g	%K x %<2µ clay	%K/%<2µ clay ratio	%K/me/100g K+ ratio
			Kenyon (P701) (continued)					
P701-11	65- 74	IIC2	25.8	2.02		52.1	0.08	
12	74- 84	IIC3	26.5	1.93		51.1	0.07	
13	84- 90	IIC4	24.8	2.04		50.6	0.08	
			Readlyn (P702)					
P702-1	0- 8	A1p	22.8[a]	1.29		29.4	0.06	
2	8- 12	A3	23.6	1.30		30.7	0.06	
3	12- 17	B1	26.3	1.19		31.3	0.05	
4	17- 24	IIB21	28.3	1.16		32.8	0.04	
5	24- 30	IIB22	27.9	1.33		37.1	0.05	
6	30- 37	IIB23	27.1	1.55		42.0	0.06	
7	37- 40	IIB3	25.9	1.70		44.0	0.07	
8	44- 50	IIC1	21.2	1.73		36.7	0.08	
9	50- 60	IIC2	14.7	1.68		24.7	0.11	
			Tripoli (P633)					
P633-1	0- 7	A1p	27.2[d]	1.23		33.5	0.05	
2	7- 11	A12	27.9	1.25		34.9	0.04	
3	11- 15	A13g	29.4	1.13		33.2	0.04	
4	15- 19	B1g	30.0	1.00		30.0	0.03	
5	19- 22	IIB1g	29.3	1.11		32.5	0.04	
6	22- 25	IIB21g	29.3	1.18		34.6	0.04	
7	25- 29	IIB22g	29.1	1.24		36.1	0.04	
8	29- 34	IIB3g	28.0	1.44		40.3	0.05	
9	34- 45	IIC1g	24.6	1.64		40.4	0.07	
10	45- 55	IIC2g	25.4	1.64		41.7	0.06	
11	55- 65	IIC3g	23.6	1.91		45.1	0.08	
12	65- 75	IIC4g	26.9	1.98		53.3	0.07	
13	75- 85	IIC5g	25.2	2.02		50.9	0.08	
14	85- 95	IIC6g	21.6	2.00		43.2	0.99	
			Russell (Ill.)					
18825	0- 4	A1	16.9[e]	2.21	0.4[e]	37.4	0.13	5.5
18826	4- 9	A2	17.0	2.23	0.2	37.9	0.13	11.2

[d]Data from Phillips (1958).
[e]Data from Bailey _et al_. (1964).

Table 5. (Continued)

Sample number	Depth (inches)	Horizon	$<2\mu$ clay %	Nonexch. K in $<1\mu$ fraction %	Exch. K^+ in whole soil me/100g	%K x $\%<2\mu$ clay	%K/% $<2\mu$ clay ratio	%K/ me/ 100g K^+ ratio
				Russell (Ill.) (continued)				
18827	9- 13	A3	23.4	2.00	0.2	46.8	0.09	10.0
18828	13- 17	B1	32.6	1.86	0.2	67.5	0.06	9.0
18829	17- 25	B21	36.9	1.52	0.2	56.1	0.04	7.6
18830	25- 38	B22	33.2	1.54	0.2	51.1	0.05	7.7
18831	38- 48	IIB31	26.9	2.48	0.2	66.7	0.09	12.4
18832	48- 57	IIB32	27.4	2.95	0.1	80.8	0.11	29.5
18833	57- 65	IIC	21.8	3.22	0.1	70.2	0.15	32.2
				Toronto				
18834	0- 7	A1	18.3[e]	1.88	0.2[e]	34.4	0.10	9.4
18835	7- 14	A2	21.5	1.82	0.1	39.1	0.08	18.2
18836	14- 17	A3	26.2	1.62	0.2	42.4	0.06	8.1
18837	17- 21	B1	33.3	1.18	0.2	39.3	0.04	5.9
18838	21- 28	B21	34.2	0.89	0.2	30.4	0.03	4.4
18839	28- 36	B22	29.7	1.05	0.2	31.2	0.04	5.2
18840	36- 45	IIB3	19.6	1.61	0.1	31.6	0.08	16.1
18841	45- 49	IIC1	22.2	3.54	0.1	78.6	0.16	35.4
18842	49- 61	IIC2	20.1	4.02	0.1	80.8	0.20	40.2
				Toronto				
18852	0- 8	A1	23.4[e]	2.42	0.3[e]	56.6	0.10	8.1
18853	8- 14	A21	24.1	2.15	0.1	51.8	0.09	21.5
18854	14- 18	A22	28.5	1.74	0.1	49.6	0.06	17.4
18855	18- 22	B1	31.8	1.56	0.1	49.6	0.05	15.6
18856	22- 29	B21	33.5	1.52	0.1	51.9	0.05	15.2
18857	29- 36	IIB22	28.9	1.70	0.2	49.1	0.06	8.5
18858	36- 45	IIB3	23.8	1.99	0.1	47.4	0.08	19.9
18859	45- 51	IIC	16.3	3.73	0.1	60.8	0.23	37.3
				Xenia				
18843	0- 4	A1	18.3[e]	2.15	0.5[e]	39.4	0.11	4.3
18844	4- 10	A2	17.4	2.12	0.2	38.5	0.12	10.6
18845	10- 14	A3	25.2	1.78	0.4	44.9	0.07	4.5
18846	14- 18	B1	28.3	1.69	0.2	47.8	0.06	8.5
18847	18- 28	B21	30.0	1.62	0.2	48.6	0.05	8.1
18848	28- 38	IIB22	25.8	1.84	0.2	47.5	0.07	9.2
18849	38- 48	IIB31	25.2	2.63	0.1	66.3	0.10	26.3
18850	48- 57	IIB32	24.2	3.02	0.1	73.1	0.12	30.2
18851	57- 70	IIC	20.7	4.27	0.1	88.4	0.21	42.7

Table 5. (Continued)

Sample number	Depth (inches)	Horizon	<2μ clay %	Nonexch. K in <1μ fraction %	Exch. K+ in whole soil me/100g	%K x %<2μ clay	%K/% <2μ clay ratio	%K/ me/ 100g K+ ratio
				Russell (Ohio, WA-37)				
10124	0- 8	Ap	20.2[f]	2.20		44.4	0.11	
10125	8- 13	A2	28.0	1.98		55.4	0.07	
10126	13- 19	B1	36.7	2.09		71.6	0.06	
10127	19- 25	B2	35.9	2.34		84.0	0.07	
10128	25- 32	IIB3	38.5	3.04		117.0	0.08	
10129	32- 38	IIC1	26.9	4.23		113.8	0.16	
10130	38- 46	IIC2a	27.9	4.42	1	125.0	0.16	
10131	46- 60	IIC2b	29.2	4.46		130.2	0.15	
				Fincastle (PB-10)				
7129	0- 8	Ap	14.9[f]	1.74		25.9	0.12	
7130	8- 11	A2	21.4	1.20		25.7	0.06	
7131	11- 14	B1	29.6	1.29		38.2	0.04	
7132	14- 19	B21	36.0	1.09		39.2	0.03	
7133	19- 24	B22	34.8	1.41		49.1	0.04	
7134	24- 28	B31	32.5	1.58		51.4	0.05	
7135	28- 32	B32	30.1	1.71		51.5	0.06	
7136	32- 36	B33	29.7	2.04		60.6	0.07	
7137	36- 40	IIC1	26.9	2.43		65.4	0.09	
7138	40- 47	IIC2	22.5	2.65		59.6	0.12	
				Till-I				
I-1	30[g]	DU[h]	21.7	2.03		44.1	0.09	
2	40[g]	UU[i]	24.1	2.00		48.2	0.08	
3	50[g]	UU	21.9	2.08		45.6	0.09	
4	100[g]	UU	12.2	3.44		42.0	0.28	
				Till-II				
II-1	5[g]	OL[j]	26.0	2.03		52.8	0.08	
2	20[g]	UU	21.4	1.43		30.6	0.07	
3	30[g]	UU	20.4	1.10		22.4	0.05	

[f]Data from Ohio Agricultural Experiment Station (Ohio Agricultural Experiment Station Staff, 1958).

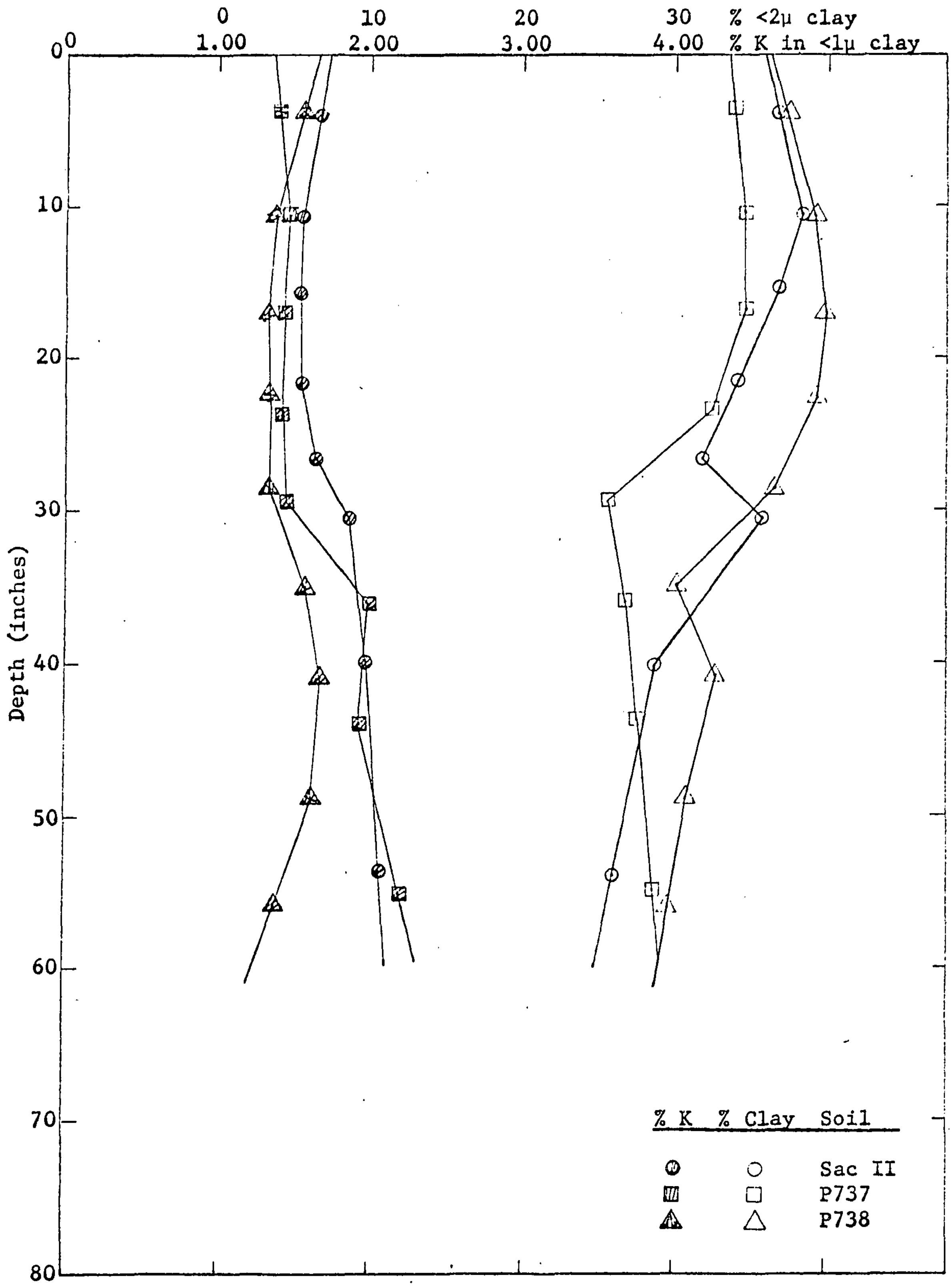
[g]Feet below surface, approximately.

[h]DU = deoxidized, unleached till.

[i]UU = unoxidized, unleached till.

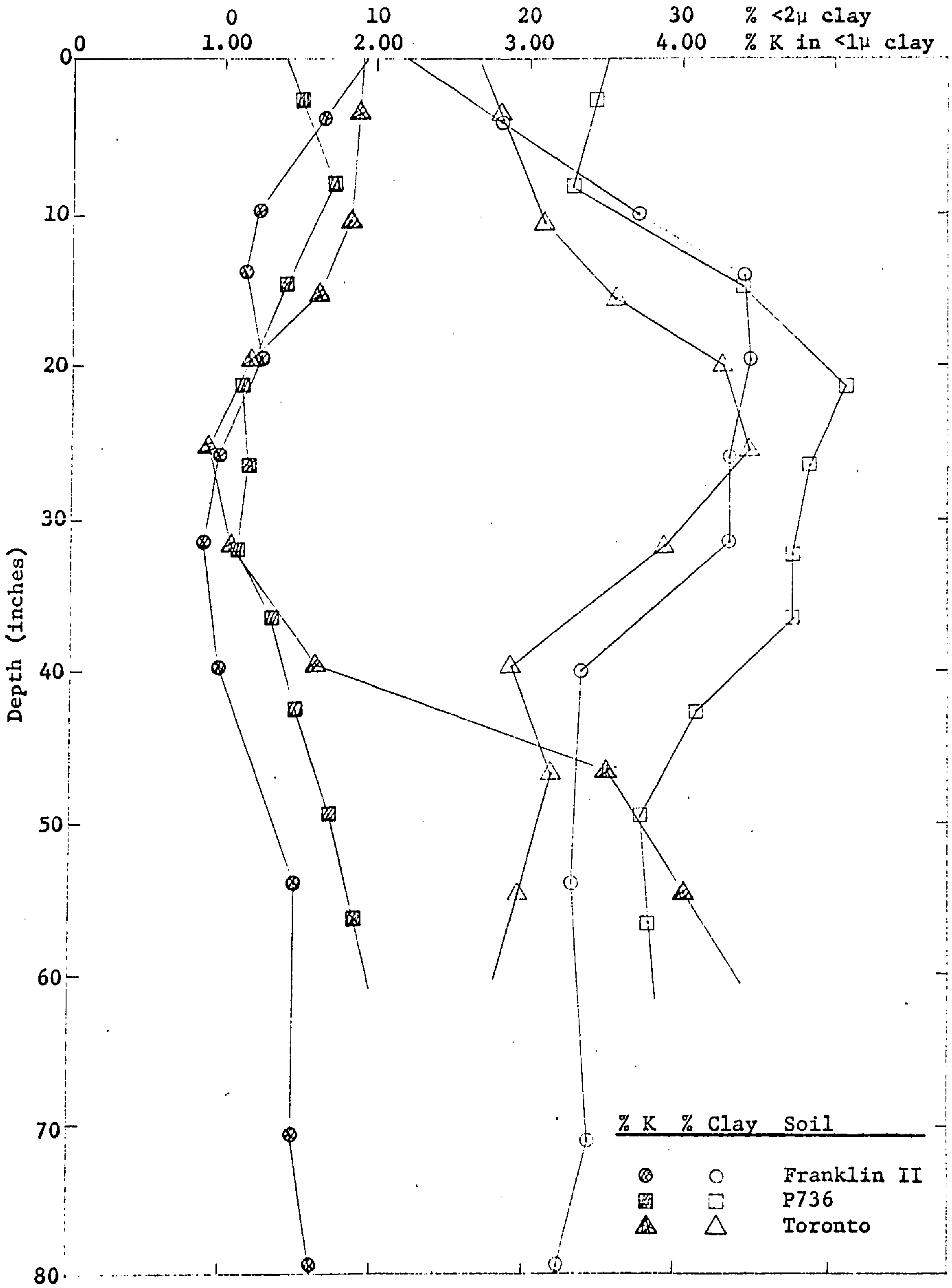
[j]OL = oxidized, leached till.

Figure 3. Profile distribution of <2μ clay and potassium in the <1μ clay in Sac II, P737 and P738; a drainage sequence with prairie vegetation from northwestern Iowa



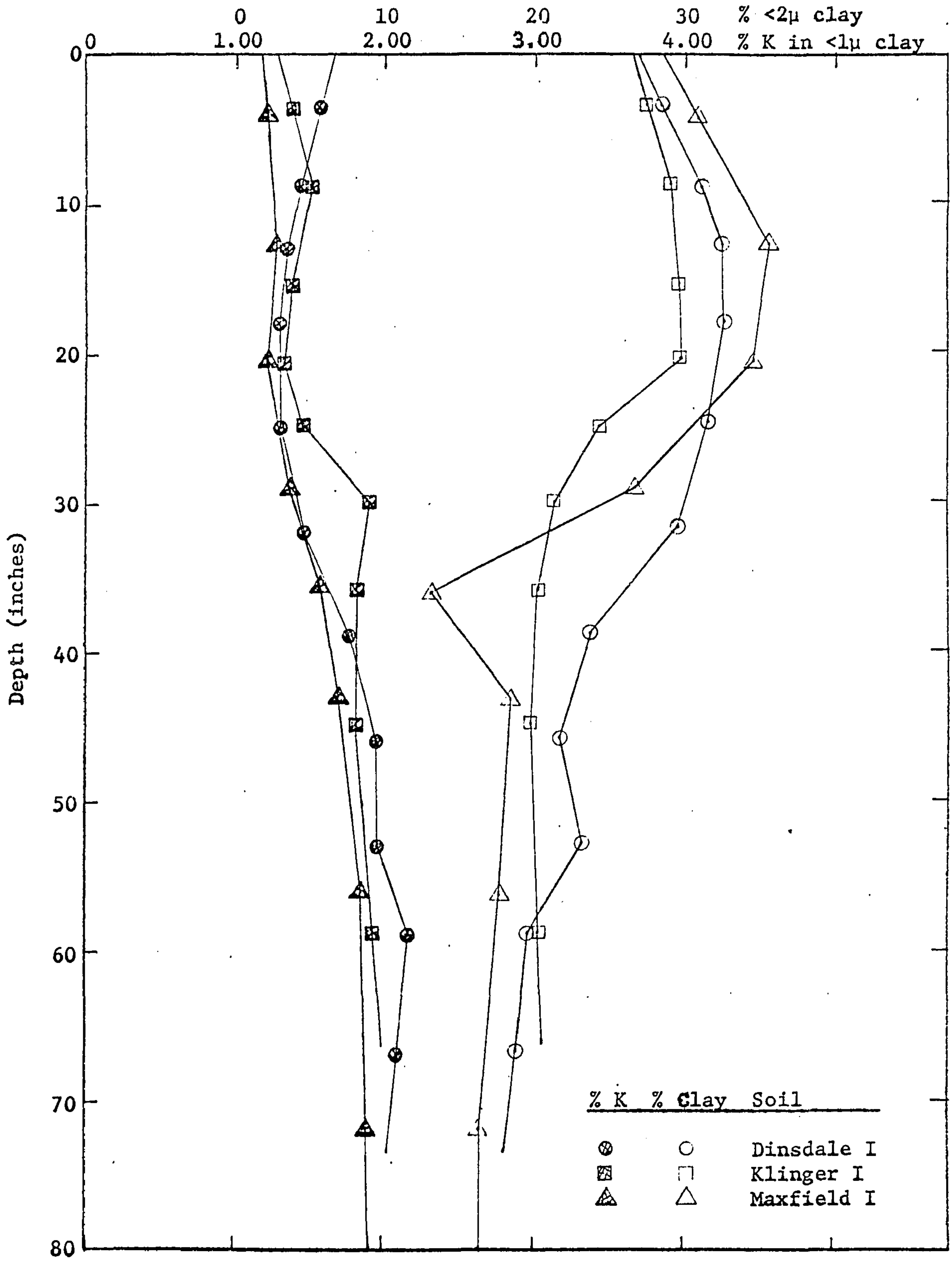
0 10 20 30 % <2μ clay
0 1.00 2.00 3.00 4.00 % K in <1μ clay
Depth (inches)
0 10 20 30 40 50 60 70 80
% K % Clay Soil
Sac II
P737
P738

Figure 4. Profile distribution of <2μ clay and potassium in the <1μ clay in Franklin II (eastern Iowa), P736 (northwestern Iowa) and Toronto (Illinois); somewhat poorly drained prairie/forest transition soils



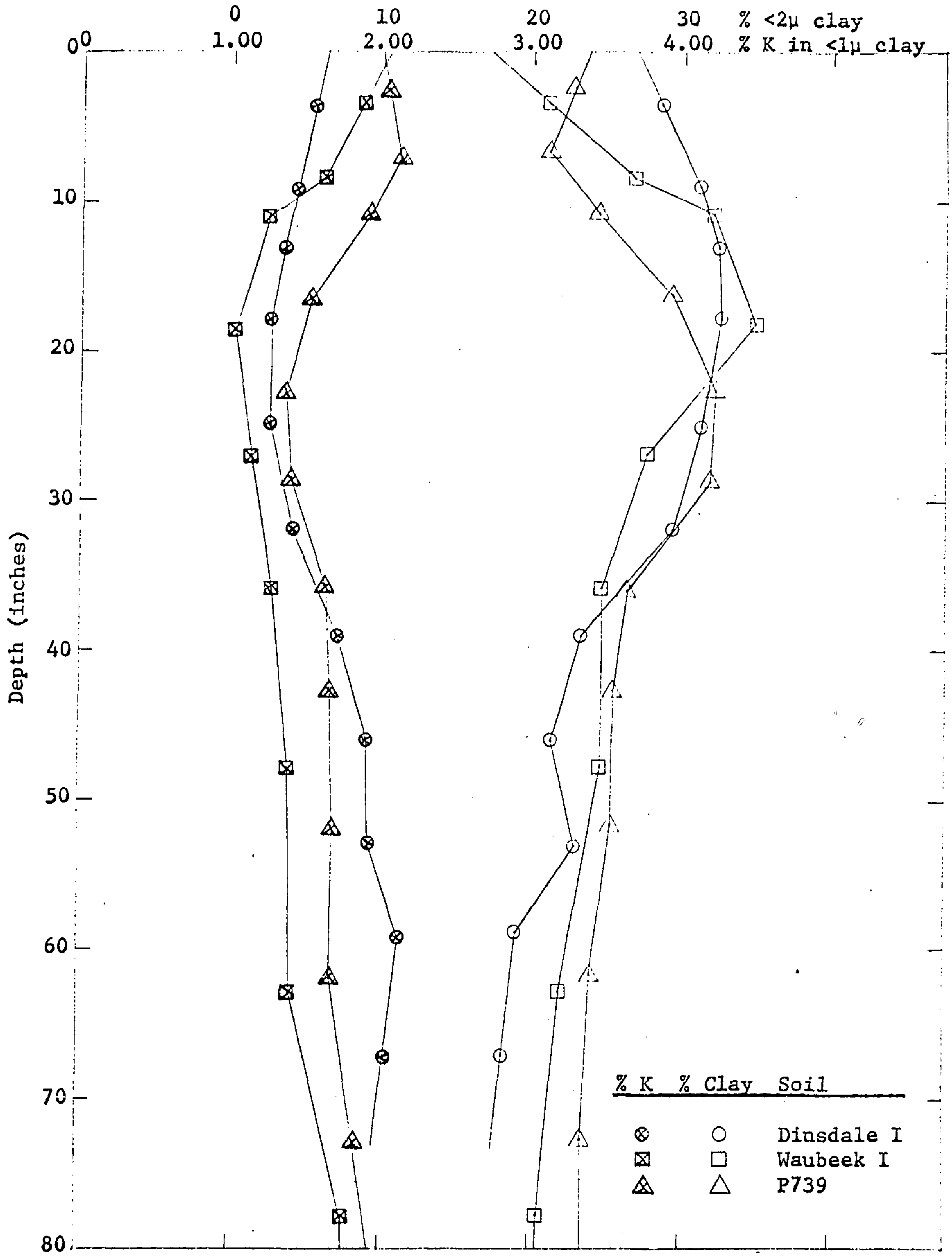
0 10 20 30 % <2μ clay
0 1.00 2.00 3.00 4.00 % K in <1μ clay
Depth (inches)
0
10
20
30
40
50
60
70
80
% K % Clay Soil
Franklin II
P736
Toronto

Figure 5. Profile distribution of the <2μ clay and potassium in the <1μ clay in Dinsdale I, Klinger I, and Maxfield I; a prairie drainage sequence from eastern Iowa



0 10 20 30 % <2μ clay
0 1.00 2.00 3.00 4.00 % K in <1μ clay
0
10
20
30
40
50
60
70
80
Depth (inches)
% K % Clay Soil
Dinsdale I
Klinger I
Maxfield I

Figure 6. Profile distribution of the $<2\mu$ clay and potassium in the $<1\mu$ clay in Dinsdale I, Waubeek I and P739; a well drained vegetation sequence from eastern Iowa



0 10 20 30 % <2μ clay
0 1.00 2.00 3.00 4.00 % K in <1μ clay
Depth (inches)
0
10
20
30
40
50
60
70
80
% K % Clay Soil
Dinsdale I
Waubeek I
P739

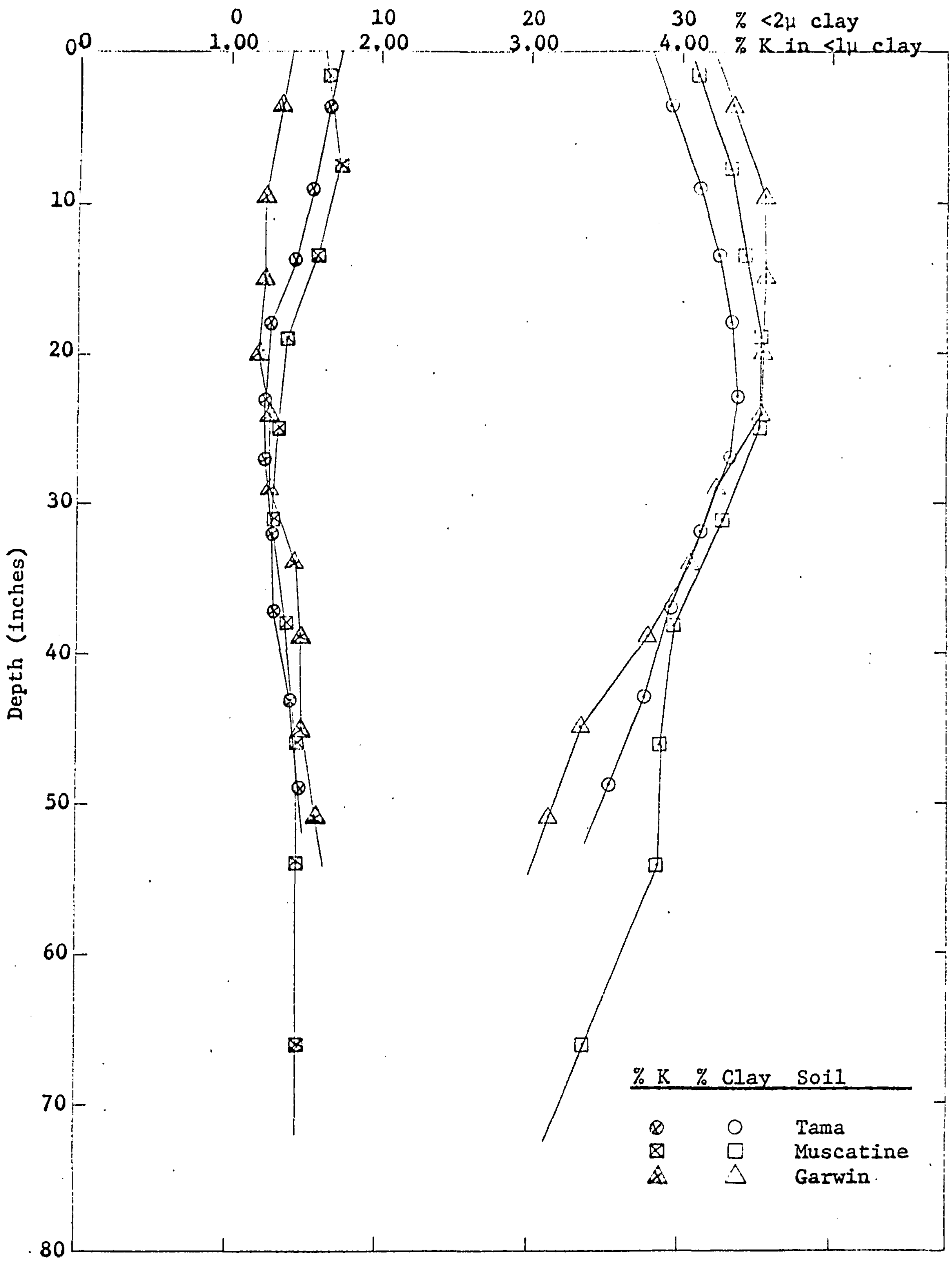
generally one stone thick such as the "stone line" discussed by Ruhe (1959).

The texture of the soils studied generally is silty clay loam, but each geographic area has characteristic clay distribution curves. The soils studied from northwestern Iowa have the highest clay content of the profile in the A horizon. The clay distribution curves for Sac II, P737 and P738 are shown in Figure 3 and for P736 in Figure 4. The clay content of the A usually ranges from approximately 37 percent in the better drained Sac soils to 40 percent in the poorly drained associate, P738. In the B horizon the clay content gradually decreases, varying from 27 to 33 percent, and becomes uniform with depth. The loess horizons contain approximately 5 to 8 percent sand and 58 to 68 percent silt, changing abruptly to 30 to 35 percent sand and 35 to 40 percent silt in the till horizons. The highest clay content is in the A horizon, so it is approximately 10 inches to the middle of the maximum clay horizon. The B/A horizon clay ratio is only 1.02 to 1.08 in the prairie profiles, indicating almost no solum textural development in these soils (Table 4). However, P736 which is a somewhat poorly drained prairie/forest transition soil, has a B/A horizon clay ratio of 1.67 and a depth of 21 inches to the middle of the clay maximum horizon.

The eastern Iowa thin loess/till soils have silt loam and silty clay loam textures too, but the clay content and profile distribution of clay are different from the northwestern Iowa soils. The clay distribution curves are shown in Figure 5 for the Dinsdale, Klinger and Maxfield profiles, in Figure 6 for the Waubeek and P739 profiles and in Figure 4 for the Franklin profile. The prairie soils are all silty clay loams, but the A horizons of the better drained Dinsdale and Klinger series range from 28 to 31 percent clay, and the poorly drained Maxfield soils from 31 to 34 percent clay. The maximum clay content is approximately 33 percent in the B horizon of the Dinsdale and Klinger soils and 35 percent in the Maxfield profiles. The prairie/forest transition soils of this area, Waubeek and Franklin, vary from 22 to 27 percent clay in the A horizon and have approximately 33 percent in the maximum clay B horizon. The well drained, forested profile, P739, varies from 21 to 24 percent clay in the A horizon and contains approximately 32 percent in the maximum clay B horizon. The thin loess/till soils of eastern Iowa range from 5 to 8 percent sand in the loess portion and from 48 to 55 percent sand in the till portion of the profile. Well and somewhat poorly drained prairie soils of eastern Iowa, Klinger and Dinsdale, have greater B/A horizon clay ratios and greater depths to the middle of the maximum clay horizon than comparable northwestern Iowa, Sac and P737, shown by Table 4.

The prairie, thick loess soils of the Tama sequence of eastern Iowa (Tama, Muscatine and Garwin) have slightly more clay in the A horizon than the prairie thin loess/till soils of eastern Iowa (Dinsdale, Klinger and Maxfield), but the amount in the B horizon is approximately the same in the two sets of soils. This is shown by the plot of clay data from Dinsdale I and Tama in Figure 8, and for Maxfield and Garwin in Figure 9. Poorly drained prairie sequence associates have finer textured surface layers as can be seen by comparing poorly drained Maxfield with well drained Dinsdale in Figure 5 and poorly drained Garwin

Figure 7. Profile distribution of the $<2\mu$ clay and potassium in the $<1\mu$ clay in Tama, Muscatine and Garwin soils; a prairie drainage sequence from eastern Iowa



0 10 20 30 % <2μ clay
0 1.00 2.00 3.00 4.00 % K in <1μ clay
0
10
20
30
40
50
60
70
80
Depth (inches)
% K % Clay Soil
Tama
Muscatine
Garwin

Figure 8. Profile distribution of the $<2\mu$ clay and potassium in the $<1\mu$ clay in Dinsdale I, Tama and Kenyon (eastern Iowa) and Sac II (northwestern Iowa); well drained prairie soils from different parent material

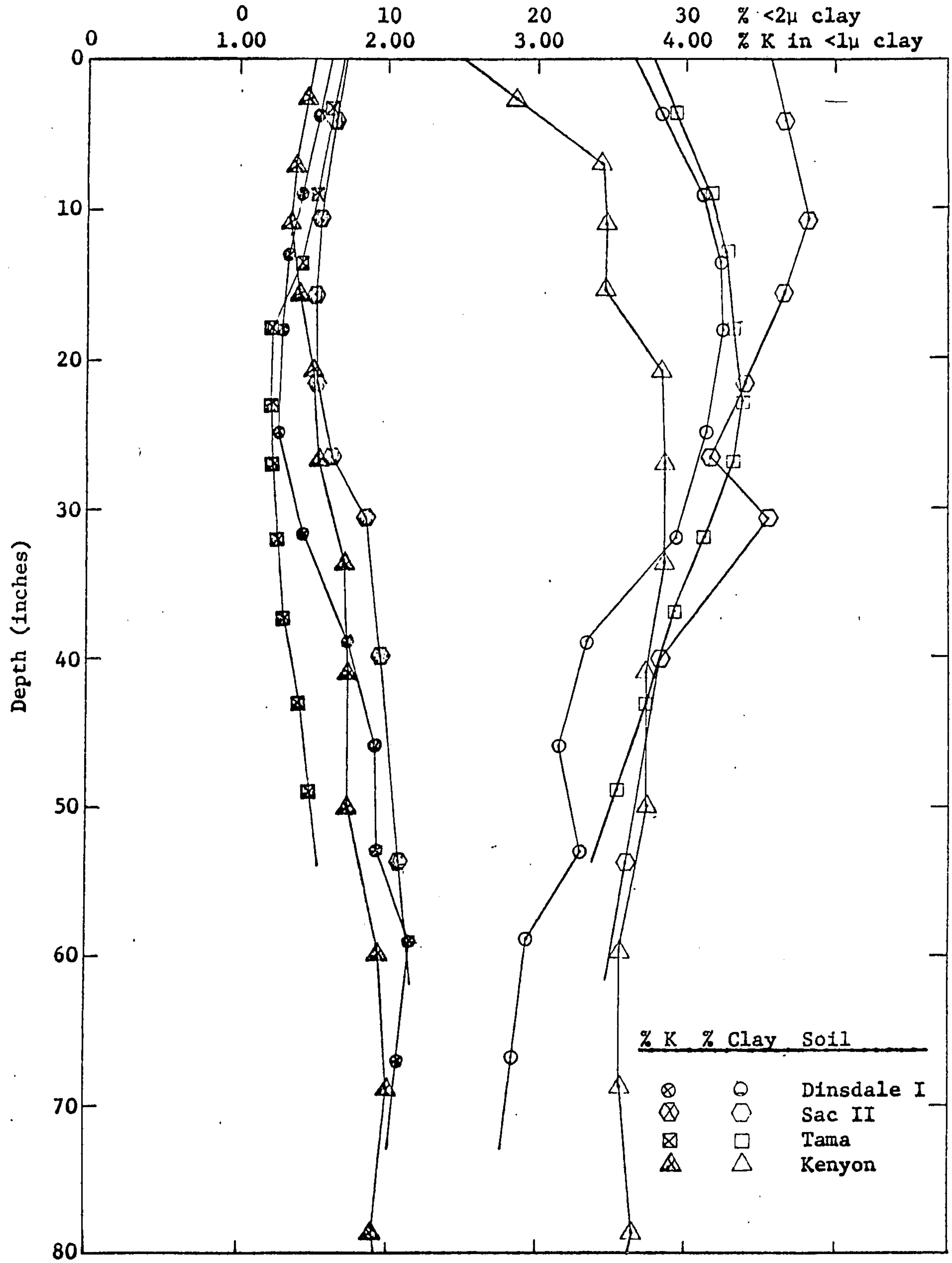
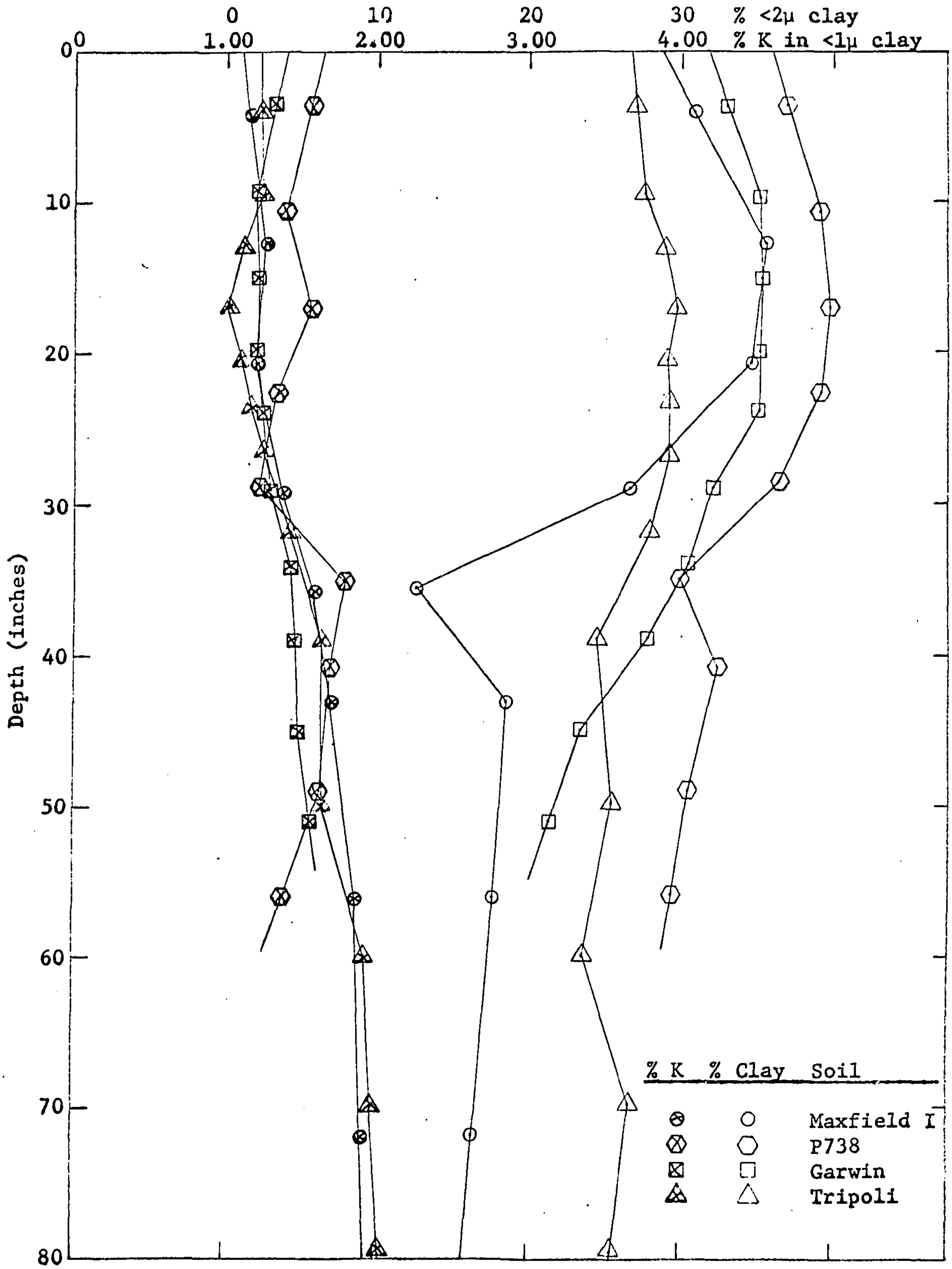

0 10 20 30 % <2μ clay
0 1.00 2.00 3.00 4.00 % K in <1μ clay
Depth (inches)
0
10
20
30
40
50
60
70
80
% K % Clay Soil
Dinsdale I
Sac II
Tama
Kenyon

Figure 9. Profile distribution of the <2μ clay and potassium in the <1μ clay in Maxfield I, Garwin and Tripoli (eastern Iowa) and P738 (northwestern Iowa); poorly drained prairie soils from different parent material



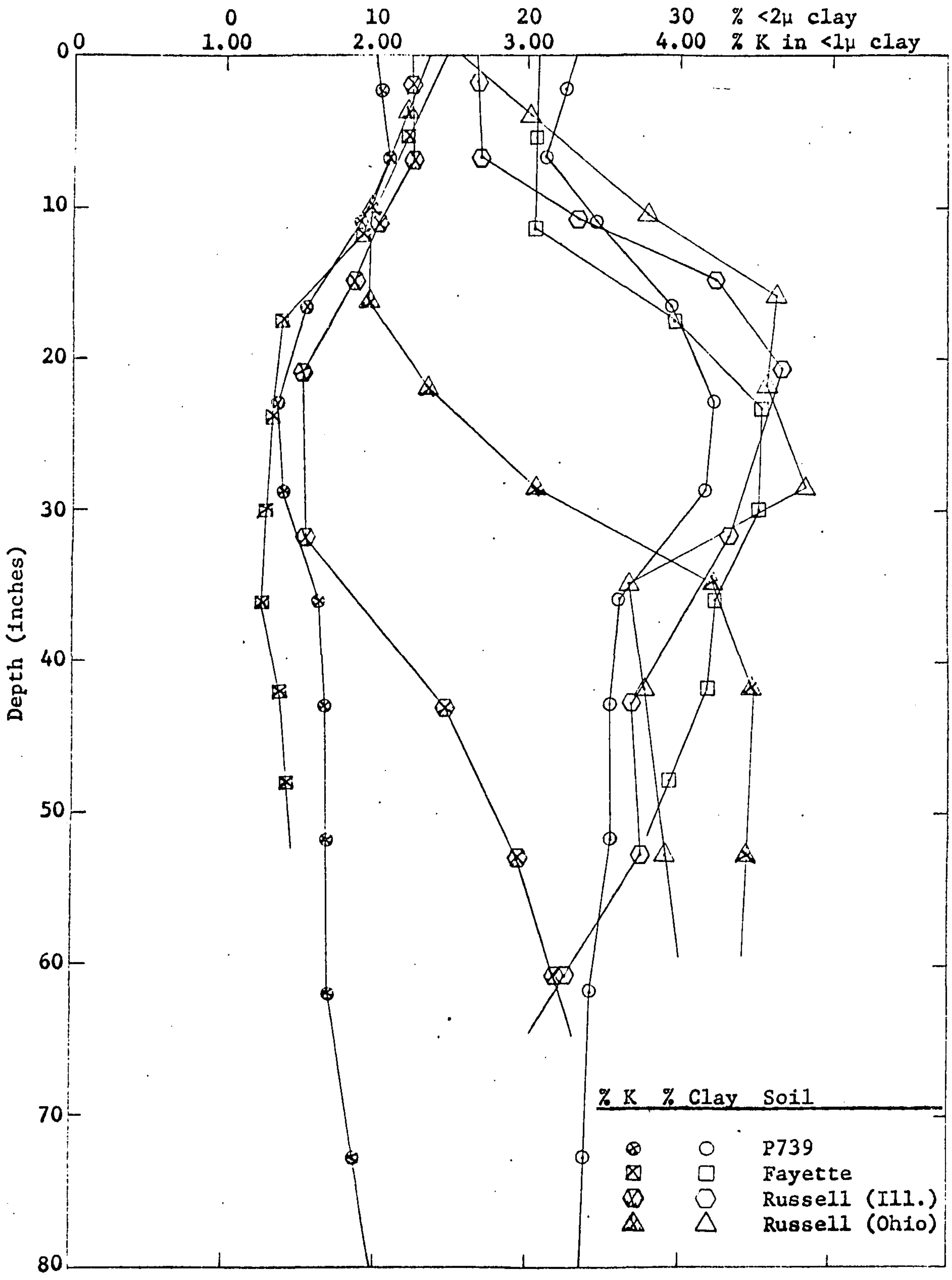
0 10 20 30 % <2µ clay
0 1.00 2.00 3.00 4.00 % K in <1µ clay
Depth (inches)
0
10
20
30
40
50
60
70
80
% K % Clay Soil
Maxfield I
P738
Garwin
Tripoli

with well drained Tama in Figure 7. The prairie soils have a silty clay loam surface texture, and the prairie/forest transition and forested series have a silt loam surface texture, as can be seen by comparing the clay data for the prairie/forest transition Waubeek and the prairie Dinsdale in Figure 6. As the forest influenced soils have about the same or slightly higher clay in the subsoil than prairie soils, they can be expected to have greater B/A horizon clay ratios than the prairie soils. In the thick loess soils the sand is low (5 to 8 percent) and the silt is high (55-65 percent) throughout the profile because the material is all loess.

The surficial sediment over till soils of the Kenyon sequence of eastern Iowa are lower in clay content and higher in sand content than the upper part of the thin loess/till soils or the thick loess soils as can be seen by comparing clay data for Kenyon, and Tama or Dinsdale in Figure 8. The Kenyon, Readlyn and Tripoli which are prairie soils, all have a loam surface texture. They have a high sand content (35 to 45 percent) in the upper horizons, but the till portion of their profiles is similar in texture to the profiles of the Dinsdale sequence. These soils have low B/A horizon clay ratios.

The Illinois and Ohio profiles are either forest or prairie/forest transition series. The clay distribution curves for both the Illinois and Ohio Russell profiles are shown in Figure 10 and the curves for the Toronto profile is shown in Figure 4. The clay content in the surface of these soils ranges from 17 to 20 percent and gradually increases, reaching a maximum in the lower B horizon with 34 to 37 percent. Then

Figure 10. Profile distribution of $<2\mu$ clay and potassium in the $<1\mu$ clay in P739 and Fayette (eastern Iowa), Russell (Illinois) and Russell (Ohio); well drained, forested thin loess/till soils


0 10 20 30 % <2μ clay
0 1.00 2.00 3.00 4.00 % K in <1μ clay
Depth (inches)
0
10
20
30
40
50
60
70
80
% K % Clay Soil
P739
Fayette
Russell (Ill.)
Russell (Ohio)

it gradually decreases to 20 to 26 percent in the lower horizons. These soils have B/A horizon clay ratios ranging from 1.6 to 2.4. The depth to the middle of the maximum clay horizon is about 21 to 29 inches. This depth to the middle of the maximum clay horizon and B/A horizon clay ratio are greater than those for comparable Iowa soils (Table 4).

Nonexchangeable Potassium

The nonexchangeable potassium, K, content of the $<1\mu$ clay fraction of the soils studied is given in Table 5. The percent K to percent $<2\mu$ clay ratio and the product of percent K times percent $<2\mu$ clay are also given in Table 5. Exchangeable potassium, K^+, and the percent K to me/100 g soil K^+ ratio are included for some profiles.

The profile distribution curves of K in the $<1\mu$ clay fraction of the northwestern Iowa prairie soils, Sac, P737 and P738, are shown in Figure 3 and the prairie/forest transition soil, P736, is shown in Figure 4. The well drained Sac soils range from 1.6 to 1.7 percent K in the A horizon, from 1.5 to 1.9 percent K in the B horizon and approximately 2.0 percent K in the C horizon. The K content of the poorly drained prairie soil, P738, is approximately 1.6 percent in the A horizon, 1.3 to 1.8 percent in the B horizon and approximately 1.6 percent in the C horizon. The somewhat poorly drained prairie/forest transition soil, P736, has a K content varying from 1.5 to 1.7 percent in the A horizon, 1.1 to 1.3 percent in the B horizon and 1.5 to 1.8 percent in the C horizon. The K content in these soils decreases slightly in the lower A and upper B horizon and then increases with depth in the IIB and lower horizons.

The profile distribution curves of the K content in the <1μ clay of the prairie thin loess/till soils of eastern Iowa, Dinsdale, Klinger and Maxfield, are shown in Figure 5. The curves of the prairie/forest transition soils are shown in Figure 6 (Waubeek) and Figure 4 (Franklin). The forested soil, P739, is shown in Figure 6. The better drained Dinsdale and Klinger soils have a K content in the <1μ fraction varying from 1.4 to 1.7 percent in the A horizon, decreasing to 1.3 to 1.4 percent in the IB horizon, and increasing to approximately 2 percent in the IIB and IIC horizons (Table 5). The poorly drained Maxfield soils have a K content varying from 1.2 to 1.3 percent in the A horizon, 1.2 to 1.7 percent in the upper B horizon and from 1.6 to 1.8 percent in the IIB or IIC horizons. The K content of the better drained prairie/forest transition soils, Waubeek and Franklin, varies from 1.4 to 1.7 percent in the A horizon, 1.0 to 1.5 percent in the upper B horizon and from 1.8 to 2.1 percent in the IIB and IIC horizons. The K content of the forested soil, P739, varies from 1.9 to 2.1 in the A horizon, 1.4 in the upper B horizon and from 1.7 to 2.0 in the IIB and IIC horizons. Generally, the northwestern Iowa soil clays have a higher K content and slightly less variation between the maximum and minimum content in the profile than the soil clays from eastern Iowa. The K content of the clays from the lower IIB and IIC till horizons are about the same for both areas.

The profile distribution of K in the <1μ clay for the thick loess soils of eastern Iowa is shown in Figure 7 for Tama, Muscatine and Garwin. The better drained prairie soils, Tama and Muscatine, have a K content varying from 1.5 to 1.7 percent in the A horizon, 1.2 to 1.4 percent in the B horizon and from 1.4 to 1.6 percent in the C horizon. The poorly drained Garwin soil has a K content ranging from 1.2 to 1.3 percent in the A horizon, 1.2 to 1.5 percent in the B horizon and approximately 1.6 percent in the C horizon. The better drained, forested soils, Fayette and Stronghurst, have a K content varying from 1.9 to 2.2 percent in the A horizon, 1.1 to 1.4 percent in the B horizon and approximately 1.4 percent in the C horizon. Generally the thick loess soils have K contents similar to the upper portion of the comparable thin loess soils, but the lower loess horizons have lower K contents than the lower horizons of the thin loess/till soils. The former have about 1.3 to 1.5 percent K, and the latter have about 2.0 percent K.

The K distribution curves for the surficial sediment soils of eastern Iowa are shown in Figure 8 (Kenyon) and Figure 9 (Tripoli). The K content of the better drained prairie soils, Kenyon and Readlyn, ranges from 1.3 to 1.5 percent in the surface, from 1.2 to 1.5 percent in the B2 horizon and from 1.7 to 2.0 percent in the IIB3 and IIC horizons. The poorly drained prairie soil, Tripoli, has a K content of 1.1 to 1.2 in the A horizon, 1.0 to 1.4 percent in the B2 horizon and 1.6 to 2.0 percent in the IIB3 and IIC horizons. Generally the K contents of the upper portion of these soils is lower than the upper portion of the thin loess/till and thick loess prairie soils. The K content of the lower till portion is similar to the till portion of the thin loess/till soils.

The profile distribution of K in the Russell soils of Illinois and Ohio is shown in Figure 10. The distribution in the Toronto profile is shown in Figure 4. Russell, the well drained forested soils from Illinois and Ohio, have a K content of 2.0 to 2.2 percent in the A horizon. The Illinois soil has a range of 1.5 to 1.8 percent in the upper B horizon and 2.5 to 3.2 percent in the IIB and IIC horizons. The Ohio Russell soil has about 2.0 percent in the upper B horizon and 4.2 to 4.5 percent in the IIB and IIC horizons. The somewhat-poorly drained, prairie/forest transition Toronto soils from Illinois have a K content range from 1.8 to 2.4 percent in the A horizon, from 0.9 to 1.9 percent in the upper B horizon, and from 3.5 to 4.0 percent in the IIB and IIC horizons. These soils have a higher K content throughout the profile and a greater difference between the maximum and minimum content in the profile than the thin loess/till soils of eastern Iowa. The till portion of the Illinois and Ohio soils has approximately twice as much K as the till portion of the Iowa soils.

Generally in the soils studied the K content of the $<1\mu$ clay fraction of the upper horizons decreases from west to east, and is in the order: northwestern Iowa > eastern Iowa > eastern Illinois > southwestern Ohio. This is in the order of increasing annual rainfall (Figures 1 and 2). However, there are differences within each area due to other environmental factors such as parent materials, drainage and vegetation. Even though there is not a large relative difference in the K content values of these soils, a very small difference is significant because the values are so small on a percentage basis, and generally they are consistent.

The K content of the $<1\mu$ clay fi ction of all of the soils studied is inversely related to the $<2\mu$ clay content and soil development as shown by the profile distribution curves in Figures 3-10 and by the percent K to percent <2μ clay ratios given in Table 5. Profile distribution curves indicate that generally the K content is decreasing in the upper horizons as the clay content is increasing, but as the clay content decreases, the K content increases until both constituents become uniform with depth in the lower horizons. The soils with strong textural development (large B/A horizon clay ratio and depth to maximum clay) such as Fayette, Russell and Toronto, have the greatest difference between maximum and minimum K content in the profile. Conversely, the smallest within profile difference is indicated by the least developed soils such as the Sac and Kenyon profiles which have low B/A clay ratios.

The K content of the <1μ clay of these soils appears to be influenced by the K content of the parent materials before weathering and alteration. The K content of the upper horizons of the thin loess/till soils of eastern Iowa (Dinsdale sequence) are similar to the K content of the upper horizons of the thick loess soils from that area (Tama sequence), but the upper horizons of the surficial sediment soils (Kenyon sequence) have a lower K content. The K content of the lower till horizons, IIC, of the thin loess/till soils of northwestern and eastern Iowa, and the surficial sediment soils are all similar, but they are higher than the lower loess, IC, horizons of the thick loess soils (Figures 8 and 9). The lower till or II horizons of the Illinois and Ohio soils have a higher K content than the till or II horizons of the Iowa soils (Figures 4 and 10).

Within a given area the better drained soils have a higher K content in the two or three horizons nearest the surface, but the lower horizons do not vary with drainage. In order of increasingly poorer drainage the K content in the upper or A horizons is: Dinsdale > Klinger > Maxfield (Figure 5) in eastern Iowa, and Sac > P737 > P738 in northwestern Iowa (Figure 3).

Comparison of a vegetation sequence shows that the forested soils have a higher K content in the upper four or five horizons than the associated prairie or prairie/forest transition soils which is illustrated by K contents in the order: P739 > Waubeek > Dinsdale (Figure 6) and Fayette > Downs > Tama.

Nonexchangeable Magnesium

The nonexchangeable magnesium, Mg, content of the $<1\mu$ clay fraction and the percent Mg to percent $<2\mu$ clay ratio of the soils studied are given in Table 6. Exchangeable magnesium (Mg^{++}), cation exchange capacity (C.E.C.) and exchangeable hydrogen (H^{+}) data and the percent Mg to me/100 g soil Mg^{++} ratio for selected soils are also given in Table 6.

Of the northwest Iowa prairie soils the better drained Sac and P737 have a Mg content in the $<1\mu$ clay fraction ranging from 1.0 to 1.1 percent in the A horizon, from 1.0 to 1.3 percent in the upper B horizon and from 1.0 to 1.2 percent in the IIB and IIC horizons. The poorly drained P738 profile has a Mg content of approximately 1.2 percent in the A horizon, from 1.2 to 1.3 percent in the upper B horizon, and approximately 1.5 percent in the IIB and IIC horizons. The profile distribution of Mg for the Sac, P737 and P738 profiles is shown in

Table 6. Nonexchangeable magnesium and related data for the soils studied

Sample number	Depth (inches)	Horizon	$<2\mu$ clay %	Non-exch. Mg in $<1\mu$ fraction %	Exch. Mg^{++} in whole soil Me/100g	C.E.C. Me/100g	Exch. H^{+} Me/100g	Base saturation %	Calculated ratios: %Mg/Me/100g Mg^{++}	Calculated ratios: %Mg/%$<2\mu$ clay
				Sac (P746)						
P746-1	0- 7	Alp	37.5[a]	1.06	5.1[a]	30.3[a]	12.9[a]	67.0[a]	0.2	0.03
2	7- 11	A3	38.4	1.05	6.1	28.6	11.4	68.0	0.2	0.03
3	11- 18	B1	37.4	1.12	6.6	26.3	9.6	72.0	0.2	0.03
4	18- 25	B21	33.6	1.29	6.3	23.8	5.8	80.0	0.2	0.04
5	25- 28	IIB22	31.7	1.20	5.8	21.6	4.3	84.0	0.2	0.04
6	28- 33	IIB23	32.0	1.03	5.3	18.8	3.0	87.0	0.2	0.03
7	33- 44	IIB3ca	33.7	0.99		15.9				0.03
8	44- 57	IICca	34.4	0.94		15.3				0.03
				Sac (P747)						
P747-1	0- 8	Alp	36.8[a]	1.04	5.5[a]	29.8[a]	10.8[a]	71.0[a]	0.2	0.03
2	8- 13	A3	38.2	1.11	6.8	27.7	9.8	73.0	0.2	0.03
3	13- 18	B1	36.8	1.19	6.7	27.1	7.8	77.0	0.2	0.03
4	18- 25	B21	34.0	1.21	6.5	24.0	5.8	81.0	0.2	0.04
5	25- 28	IIB22	31.7	1.21	5.6	20.3	4.0	84.0	0.2	0.04
6	28- 33	IIB23	35.5	1.07	5.6	19.8	2.8	88.0	0.2	0.03
7	33- 47	IIB3ca	28.2	0.96		13.9				0.03
8	47- 60	IICca	25.6	0.99		12.7				0.04
				P737 (Unnamed soil no. 282)						
P737-1	0- 7	Alp	34.0	1.09						0.03
2	7- 14	A12	34.8	1.20						0.03
3	14- 20	A3	34.7	1.17						0.03
4	20- 27	B1	32.6	1.29						0.04
5	27- 32	B2	25.0	1.40						0.06
6	32- 40	IIC1	27.0	1.36						0.05
7	40- 49	IIC2	27.6	1.16						0.04
8	49- 60	IIC3	28.4	1.20						0.04

[a]Data from Lincoln Soil Survey Laboratory (U.S. Soil Survey Staff, 1966).

Table 6. (Continued)

Sample number	Depth (inches)	Hori-zon	<2μ clay %	Non-exch. Mg in <1μ fraction %	Exch. Mg++ in whole soil Me/100g	C.E.C. Me/100g	Exch. H+ Me/100g	Base saturation %	Calculated ratios: %Mg/Me/100g Mg++	Calculated ratios: %Mg/%<2μ clay
				P738 (Unnamed soil no. 191)						
P738-1	0- 7	A1p	37.1	1.18						0.03
2	7- 14	A12	39.4	1.18						0.03
3	14- 20	A3	40.0	1.17						0.03
4	20- 25	B1	39.2	1.24						0.03
5	25- 32	B2g	36.7	1.26						0.03
6	32- 38	IIB3	30.0	1.35						0.05
7	38- 45	IIC1	32.6	1.46						0.04
8	45- 52	IIC2	30.6	1.47						0.05
9	52- 60	IIC2	29.5	1.47						0.05
				P736 (Unnamed soil no. 282F)						
P736-1	0- 6	A1	24.6	0.85						0.03
2	6- 11	A21	23.0	1.00						0.04
3	11- 19	A22	34.4	1.04						0.03
4	19- 24	B1	41.0	0.95						0.02
5	24- 30	B21	38.7	0.94						0.02
6	30- 35	IIB22	37.6	0.85						0.02
7	35- 39	IIB23	37.8	0.82						0.02
8	39- 47	IIC1	31.1	0.95						0.03
9	47- 54	IIC2	27.6	1.09						0.04
10	54- 60	IIC2	28.2	1.06						0.04
				Dinsdale (P704)						
P704-1	0- 7	A1p	28.8[a]	0.90	4.4[a]	21.4[a]	10.2[a]	65.0[a]	0.2	0.03
2	7- 11	A12	31.2	0.98	4.2	20.7	11.2	60.0	0.2	0.03
3	11- 15	A3	32.7	0.95	5.2	21.2	10.0	65.0	0.2	0.03
4	15- 21	B1	32.9	1.02	5.2	21.3	8.6	69.0	0.2	0.03
5	21- 29	B2	31.7	1.04	5.3	21.0	7.7	71.0	0.2	0.03
6	29- 36	B31	29.7	1.09	5.3	19.8	6.2	76.0	0.2	0.04
7	36- 43	IIB32	23.6	1.10	2.7	11.2	3.1	78.0	0.4	0.05
8	43- 50	IIB33	21.7	1.07	2.8	11.2	2.6	81.0	0.4	0.05
9	50- 56	IIC1	23.1	0.93		11.2				0.04
10	56- 62	IIC2	19.5	0.95		9.2				0.05
11	62- 73	IIC3	18.7	0.93		8.7				0.05

Table 6. (Continued)

Sample number	Depth (inches)	Horizon	<2μ clay %	Non-exch. Mg in <1μ fraction %	Exch. Mg++ in whole soil Me/100g	C.E.C. Me/100g	Exch. H+ Me/100g	Base saturation %	Calculated ratios: %Mg/Me/100g Mg++	Calculated ratios: %Mg/%<2μ clay
				Dinsdale (P705)						
P705-1	0- 6	A1p	29.2[a]	0.92	4.2[a]	20.5[a]	9.3[a]	67.0[a]	0.2	0.03
2	6- 12	A3	33.1	1.01	5.8	21.7	9.6	67.0	0.2	0.03
3	12- 16	B1	33.4	0.98	5.6	22.2	9.1	69.0	0.2	0.03
4	16- 21	B21	32.9	0.95	6.0	22.5	7.9	72.0	0.2	0.03
5	21- 26	B22	29.2	1.07	5.6	20.2	6.4	75.0	0.2	0.04
6	26- 30	B23	23.9	1.07	4.3	15.4	4.5	77.0	0.2	0.04
7	30- 37	IIB31	22.3	1.01	3.3	12.2	2.6	83.0	0.3	0.05
8	37- 44	IIB32	25.2	1.05	3.9	14.2	1.6	90.0	0.3	0.04
9	44- 48	IIB33	22.7	1.16		12.5				0.05
10	48- 58	IIC1	21.0	1.05		10.6				0.05
11	58- 66	IIC2	20.8	0.97		10.0				0.05
				Klinger (P706)						
P706-1	0- 7	A1p	27.5[a]	0.96	5.2[a]	26.2[a]	11.5[a]	69.0[a]	0.2	0.03
2	7- 13	A12	29.2	1.10	4.6	25.2	11.0	68.0	0.2	0.04
3	13- 18	A3	29.8	1.17	5.0	23.0	7.4	76.0	0.2	0.04
4	18- 23	B1	29.8	1.02	5.0	21.6	4.3	84.0	0.2	0.03
5	23- 28	B21	24.2	0.84	4.4	18.0	2.4	90.0	0.2	0.03
6	28- 33	B22	21.1	1.06	3.8	16.3	1.9	90.0	0.3	0.05
7	33- 40	IIB3	20.1	1.00		10.5				0.05
8	40- 50	IIC1	19.6	0.95		9.3				0.05
9	50- 68	IIC2	19.9	0.71		9.2				0.04
				Klinger (P707)						
P707-1	0- 9	A1	28.9[a]	1.01	5.0[a]	24.8[a]	12.7[a]	62.0[a]	0.2	0.03
2	9- 13	A3	28.1	1.00	3.6	20.2	10.0	63.0	0.3	0.04
3	13- 19	B1	31.1	0.91	4.4	20.9	7.9	71.0	0.2	0.03
4	19- 26	B21	30.6	0.99	5.2	21.5	4.5	84.0	0.2	0.03
5	26- 31	B22	26.8	1.11	4.8	19.9	3.6	86.0	0.2	0.04
6	31- 36	IIB31	20.9	1.27	2.8	11.4	1.6	89.0	0.5	0.06
7	36- 40	IIB32	25.6	1.02	3.1	13.1	1.6	90.0	0.3	0.04
8	40- 46	IIB33	28.1	0.99	3.3	13.9	1.6	91.0	0.3	0.04
9	46- 52	IIC1	27.9	0.86	3.2	13.4	1.2	92.0	0.3	0.03
10	52- 64	IIC2	26.9	0.76		12.6				0.03

Table 6. (Continued)

Sample number	Depth (inches)	Hori-zon	<2µ clay %	Non-exch. Mg in <1µ fraction %	Exch. Mg++ in whole soil Me/100g	C.E.C. Me/100g	Exch. H+ Me/100g	Base saturation %	Calculated ratios: %Mg/Me/100g Mg++	Calculated ratios: %Mg/%<2µ clay
				Maxfield (P733)						
P733-1	0- 8	A1p	31.0	0.89						0.03
2	8- 17	A12	35.8	0.93	6.9				0.1	0.03
3	17- 24	A3	34.6	1.12	6.5				0.2	0.03
4	24- 34	B2g	26.9	1.24	5.5				0.2	0.05
5	34- 37	IIB31	12.4	1.14	1.9				0.6	0.09
6	37- 48	IIB32	18.4	1.00	2.4				0.4	0.05
7	48- 64	IIC1	17.7	0.95						0.05
8	64- 80	IIC2	16.3	0.88						0.05
9	80- 97	IIC2	16.5	0.89						0.05
10	97-106	IIC3	23.1	1.02						0.04
				Maxfield (P734)						
P734-1	0- 7	A1p	32.9	0.83						0.03
2	7- 13	A12	33.0	0.84						0.03
3	13- 20	A13	33.3	0.98						0.03
4	20- 25	A3	32.2	1.03						0.03
5	25- 33	B2g	27.3	0.93						0.03
6	33- 38	IIB31	16.0	1.09						0.07
7	38- 48	IIB32	21.3	0.90						0.04
8	48- 62	IIC1	25.0	0.85						0.03
9	62- 74	IIC2	23.2	0.86						0.04
10	74- 86	IIC2	24.8	0.88						0.04
11	86-101	IIC2	23.7	0.87						0.04
12	101-117	IIC3	25.5	0.84						0.03
13	117-125	IIC4	25.3	0.83						0.03
14	125-131	IIC5	25.6	0.80						0.03
15	131-148	IIC6	25.3	0.86						0.03
16	148-172	IIC6	25.3	0.85						0.03
17	172-184	IIC7	26.3	0.94						0.04
				Waubeek (P732)						
P732-1	0- 7	A1p	21.4	1.05						0.05
2	7- 9½	A2	27.2	1.06						0.04
3	9½- 14	B1	32.5	0.94	5.0				0.2	0.03
4	14- 23	B21	35.1	0.92	5.8				0.2	0.03
5	23- 31	B22	28.8	0.98	4.6				0.2	0.03

Table 6. (Continued)

Sample number	Depth (inches)	Hori- zon	$<2\mu$ clay %	Non- exch. Mg in $<1\mu$ frac- tion %	Exch. Mg^{++} in whole soil Me/ 100g	C.E.C. Me/ 100g	Exch. H^+ Me/ 100g	Base satu- ration %	Calculated ratios: %Mg/ Me/ 100g Mg^{++}	Calculated ratios: %Mg/ $\%<2\mu$ clay
				Waubeek (P732) (continued)						
P732-6	31- 41	IIB23	25.2	0.93	3.6				0.3	0.04
7	41- 55	IIB3	25.2	0.85	3.6				0.2	0.03
8	55- 72	IIC1	22.8	0.94	3.1				0.3	0.04
9	72- 85	IIC2	20.4	1.05						0.05
10	85- 98	IIC2	20.6	1.05						0.05
11	98-122	IIC3	18.0	1.01						0.06
				Waubeek (P735)						
P735-1	0- 6	A1p	19.2	0.99						0.05
2	6- 9	A21	19.4	1.02						0.05
3	9- 14	A22	24.9	1.00						0.04
4	14- 21	B1	27.8	1.00						0.04
5	21- 28	B21	29.3	1.04						0.04
6	28- 32	B22	29.6	1.05						0.04
7	32- 38	IIB23	25.0	0.84						0.03
8	38- 44	IIB31	26.8	0.75						0.03
9	44- 54	IIB32	27.1	0.81						0.03
10	54- 67	IIC1	27.0	0.90						0.03
11	67- 81	IIC2	27.7	0.87						0.03
12	81- 92	IIC3	23.6	0.86						0.04
13	92-104	IIC3	27.7	0.92						0.03
				Franklin (P730)						
P730-1	0- 6	A1p	24.7	0.90						0.04
2	6- 9	A12	25.4	0.86						0.03
3	9- 16	A2	28.2	0.79	3.5				0.2	0.03
4	16- 22	B1	32.0	0.88	4.5				0.2	0.03
5	22- 32	B21	31.4	0.82	4.9				0.2	0.03
6	32- 42	IIB22	22.7	0.87	2.6				0.3	0.04
7	42- 49	IIB3	22.1	0.93	2.4				0.4	0.04
8	49- 68	IIC1	20.7	0.92	2.3				0.4	0.04
9	68- 90	IIC2	16.4	0.97						0.06
10	90-110	IIC3	15.2	1.08						0.07

Table 6. (Continued)

Sample number	Depth (inches)	Horizon	<2µ clay %	Non-exch. Mg in <1µ fraction %	Exch. Mg++ in whole soil Me/100g	C.E.C. Me/100g	Exch. H+ Me/100g	Base saturation %	Calculated ratios: %Mg/Me/100g Mg++	Calculated ratios: %Mg/%<2µ clay
				Franklin (P731)						
P731-1	0- 8	A1p	18.4	0.94						0.05
2	8- 12	A12	27.2	0.85						0.03
3	12- 16	B1	34.1	1.10	5.1				0.2	0.03
4	16- 23	B21	34.8	1.16	5.6				0.2	0.03
5	23- 29	B22	33.4	0.81	5.6				0.1	0.02
6	29- 34	B23	33.3	0.80	6.0				0.1	0.02
7	34- 46	IIB31	23.7	0.86	4.0				0.2	0.04
8	46- 62	IIB32	23.2	1.08	3.8				0.3	0.05
9	62- 80	IIC1	24.4	1.03	4.1				0.3	0.04
10	80- 96	IIC2	20.4	0.96						0.05
11	96-112	IIC2	20.3	0.97						0.05
				P739 (Unnamed soil no. 481)						
P739-1	0- 5	A1	22.8	1.06						0.05
2	5- 9	A21	21.1	0.97						0.05
3	9- 13	A22	24.5	1.07						0.04
4	13- 20	B1	29.6	0.97						0.03
5	20- 26	B21	32.2	1.01						0.03
6	26- 33	B22	31.9	1.03						0.03
7	33- 39	IIB23	26.0	0.76						0.03
8	39- 47	IIB3	25.4	0.81						0.03
9	47- 57	IIC1	25.3	0.89						0.04
10	57- 68	IIC2	24.0	0.92						0.04
11	68- 79	IIC3	23.6	0.89						0.04
12	79- 90	IIC3	23.8	0.93						0.04
13	90-105	IIC4	23.3	0.69						0.03
14	105-120	IIC4	22.8	0.76						0.03
				Tama (Pal-1)						
Pal-1-1	0- 7	Ap	29.2[b]	1.04				70.0[b]		0.04
2	7- 11	A12	31.2	1.06				70.7		0.03
3	11- 16	A3	32.4	1.09				74.6		0.03
4	16- 21	B1	33.2	1.15				76.2		0.03
5	21- 25	B21	33.8	1.19				79.4		0.04

[b]Data from Fenton (1966).

Table 6. (Continued)

Sample number	Depth (inches)	Horizon	<2μ clay %	Non-exch. Mg in <1μ fraction %	Exch. Mg++ in whole soil Me/100g	C.E.C. Me/100g	Exch. H+ Me/100g	Base saturation %	Calculated ratios — %Mg/Me/100g Mg++	%Mg/%<2μ clay
				Tama (Pal-1) (continued)						
Pal-1-6	25- 29	B22	33.2	1.23				83.4		0.04
7	29- 34	B23	31.2	1.28				84.2		0.04
8	34- 40	B31	29.1	1.33				88.1		0.05
9	40- 46	B32	27.6	1.35				88.7		0.05
10	46- 52	C	25.2	1.39				91.5		0.06
				Muscatine (P-94)						
P-94-1	0- 3	A1	31.0[c]	1.04						0.03
3	6- 9	A1	33.9	1.03						0.03
5	12- 15	A1	34.2	1.05						0.03
7	18- 21	B1	35.3	1.04						0.03
9	24- 27	B2	35.0	1.19						0.03
11	30- 33	B2	32.7	1.12						0.03
13	36- 40	B3	29.7	1.24						0.04
15	44- 48	C1	28.8	1.21						0.04
17	52- 56	C1	28.5	1.30						0.05
19	62- 70	C1	23.7	1.36						0.06
				Garwin (Pal-3)						
Pal-3-1	0- 7	Ap	33.3[b]	1.06				90.3		0.03
2	7- 12	A12	35.5	1.07				91.1		0.03
3	12- 18	A3	35.6	1.13				93.0		0.03
4	18- 22	B1	35.3	1.17				94.4		0.03
5	22- 27	B21g	35.2	1.21				95.6		0.03
6	27- 31	B22g	32.3	1.31				96.1		0.04
7	31- 36	B22g	30.8	1.31				97.0		0.04
8	36- 42	B31g	27.9	1.35				97.8		0.05
9	42- 48	B32g	23.3	1.43				98.4		0.06
10	48- 54	C	21.2	1.46						0.07

[c]Data from Corliss (1958).

Table 6. (Continued)

Sample number	Depth (inches)	Horizon	<2µ clay %	Non-exch. Mg in <1µ fraction %	Exch. Mg++ in whole soil Me/100g	C.E.C. Me/100g	Exch. H+ Me/100g	Base saturation %	Calculated ratios: %Mg/Me/100g Mg++	Calculated ratios: %Mg/%<2µ clay
				Downs (P428)						
P428-1	0- 3	A1	23.1[c]	0.89						0.04
2	3- 6	A21	23.6	0.93						0.04
3	6- 9	A22	24.7	0.92						0.04
4	9- 12	A23	26.8	0.95						0.04
5	12- 15	A31	30.2	0.91						0.03
6	15- 18	B1	31.1	0.97						0.03
7	18- 22	B21	35.6	0.91						0.03
8	22- 26	B22	34.6	0.98						0.03
9	26- 30	B22	33.8	1.00						0.03
10	30- 34	B22	31.9	1.04						0.03
11	34- 40	B3	31.1	1.08						0.03
12	40- 46	C1	30.0	1.00						0.03
13	46- 52	C1	30.3	1.03						0.03
				Atterberry (P608)						
P608-1	0- 4	Ap	21.1[c]	1.16						0.05
2	4- 7	Ap	21.2	1.14						0.05
3	7- 11	A2	23.2	1.14						0.05
4	11- 15	A2	24.4	1.13						0.05
5	15- 19	A3	26.2	1.10						0.04
6	19- 24	B1	32.1	0.99						0.03
7	24- 29	B2	35.2	1.15						0.03
8	29- 35	B2	35.4	1.09						0.03
9	35- 41	B3	31.9	1.14						0.04
10	41- 54	B3	31.0	1.21						0.04
11	54- 68	C	29.0	1.31						0.05
				Walford (P607)						
P607-1	0- 4	Ap	18.9[c]	0.94						0.05
2	4- 8	A2	18.5	0.96						0.05
3	8- 10	A2	22.7	0.92						0.04
4	10- 12	A2	24.8	1.00						0.04
5	12- 15	B1	30.0	1.02						0.03
6	15- 18	B21	36.8	0.94						0.03
7	18- 22	B22	40.9	0.93						0.02
8	22- 25	B23	38.9	0.91						0.02
9	25- 31	B23	38.1	0.96						0.03

Table 6. (Continued)

Sample number	Depth (inches)	Horizon	<2μ clay %	Non-exch. Mg in <1μ fraction %	Exch. Mg++ in whole soil Me/100g	C.E.C. Me/100g	Exch. H+ Me/100g	Base saturation %	Calculated ratios: %Mg/Me/100g Mg++	Calculated ratios: %Mg/%<2μ clay
				Walford (P607) (continued)						
P607-10	31- 38	B3	36.8	0.94						0.03
11	38- 45	B3	35.1	0.93						0.03
12	45- 51	C	32.1	1.05						0.03
13	51- 62	C	27.3	1.41						0.05
				Fayette (P32)						
P32-3	4- 7	A21	20.6[c]	1.06						0.05
5	10- 13	A3	20.5	1.04						0.05
7	16- 19	B1	29.7	0.93						0.03
9	22- 25	B22	35.5	0.98						0.03
11	28- 31	B22	35.3	1.04						0.03
13	34- 37	B31	32.3	1.07						0.03
15	40- 43	B32	31.5	1.09						0.03
17	46- 49	C1	29.4	1.09						0.04
				Stronghurst (P609)						
P609-1	0- 4	Ap	17.1[c]	0.91						0.05
2	4- 7	A2	17.2	0.98						0.06
3	7- 11	A2	21.0	1.04						0.05
4	11- 15	A2	27.6	1.01						0.04
5	15- 18	B1	33.9	0.97						0.03
6	18- 22	B2	38.7	0.95						0.02
7	22- 25	B2	38.2	0.96						0.03
8	25- 29	B2	36.5	0.90						0.02
9	29- 33	B3	35.0	0.95						0.03
10	33- 38	B3	32.9	0.99						0.03
11	38- 45	B3	31.6	1.06						0.03
12	45- 53	C1	30.4	1.06						0.03
13	53- 65	C1	31.4	1.17						0.04
				Traer (P422)						
P422-1	0- 7	Ap	18.4[c]	1.03						0.06
2	7- 10	A2	23.8	1.10						0.05
3	10- 13	B1	30.9	1.04						0.03
4	13- 19	B2	38.7	1.11						0.03
5	19- 23	B2	39.5	1.05						0.03

Table 6. (Continued)

Sample number	Depth (inches)	Horizon	<2µ clay %	Non-exch. Mg in <1µ fraction %	Exch. Mg++ in whole soil Me/100g	C.E.C. Me/100g	Exch. H+ Me/100g	Base saturation %	Calculated ratios: %Mg/Me/100g Mg++	Calculated ratios: %Mg/%<2µ clay
				Traer (P422) (continued)						
P422-6	23- 29	B3	35.9	1.14						0.03
7	29- 35	C1	34.4	1.11						0.03
8	35- 41	C1	33.4	1.19						0.04
9	41- 50	Cca	29.1	1.44						0.05
10	50- 55	Cca	24.1	1.45						0.06
				Kenyon (P701)						
P701-1	0- 5	A1p1	18.4[a]	0.88	2.6[a]	14.0[a]	9.2[a]		0.3	0.05
2	5- 9	A1p2	24.4	0.92	2.1	15.9	11.2		0.4	0.04
3	9- 13	A3	24.6	0.93	1.7	14.5	8.8		0.5	0.04
4	13- 18	IIB1	24.5	0.94	1.6	13.1	6.2		0.6	0.04
5	18- 24	IIB2	28.5	0.87	1.7	14.8	4.5		0.5	0.03
6	24- 30	IIB22	28.8	0.87	1.7	14.0	3.1		0.5	0.03
7	30- 37	IIB23	28.5	0.91	1.5	13.4	3.1		0.6	0.03
8	37- 45	IIB31	27.4	0.91	1.6	13.3	2.1		0.6	0.03
9	45- 55	IIB32	27.3	0.96	1.6	13.0	1.9		0.6	0.04
10	55- 65	IIC1	25.2	0.99	1.3	12.0	1.2		0.8	0.04
11	65- 74	IIC2	25.8	1.00	1.4	11.8	1.2		0.7	0.04
12	74- 84	IIC3	26.5	0.95		11.4				0.04
13	84- 90	IIC4	24.8	0.97		10.8				0.04
				Readlyn (P702)						
P702-1	0- 8	A1p	22.8[a]	0.81						0.04
2	8- 12	A3	23.6	0.91						0.04
3	12- 17	B1	26.3	0.93						0.04
4	17- 24	IIB21	28.3	0.93						0.03
5	24- 30	IIB22	27.9	0.88						0.03
6	30- 37	IIB23	27.1	1.01						0.04
7	37- 40	IIB3	25.9	1.05						0.04
8	44- 50	IIC1	21.2	1.05						0.05
9	50- 60	IIC2	14.7	1.24						0.08

Table 6. (Continued)

Sample number	Depth (inches)	Horizon	<2μ clay %	Non-exch. Mg in <1μ fraction %	Exch. Mg++ in whole soil Me/100g	C.E.C. Me/100g	Exch. H+ Me/100g	Base saturation %	Calculated ratios: %Mg/Me/100g Mg++	Calculated ratios: %Mg/%<2μ clay
				Tripoli (P633)						
P633-1	0- 7	A1p	27.2[d]	1.07						0.04
2	7- 11	A12	27.9	1.00						0.04
3	11- 15	A13g	29.4	0.82						0.03
4	15- 19	B1g	30.0	0.79						0.03
5	19- 22	IIB1g	29.3	0.91						0.03
6	22- 25	IIB21g	29.3	0.88						0.03
7	25- 29	IIB22g	29.1	0.97						0.03
8	29- 34	IIB3g	28.0	1.15						0.04
9	34- 45	IIC1g	24.6	1.05						0.04
10	45- 55	IIC2g	25.4	0.96						0.04
11	55- 65	IIC3g	23.6	1.06						0.04
12	65- 75	IIC4g	26.9	1.03						0.04
13	75- 85	IIC5g	25.2	1.03						0.04
14	85- 95	IIC6g	21.6	1.09						0.05
				Russell (Ill.)						
18825	0- 4	A1	16.9[e]	1.09	3.2[e]	22.0[e]			0.3	0.06
18826	4- 9	A2	17.0	0.96	1.7	11.6			0.6	0.06
18827	9- 13	A3	23.4	1.10	3.6	14.0			0.3	0.05
18828	13- 17	B1	32.6	1.21	6.2	20.5			0.2	0.04
18829	17- 25	B21	36.9	1.20	6.6	26.2			0.2	0.03
18830	25- 38	B22	33.2	1.21	6.6	24.9			0.2	0.04
18831	38- 48	IIB31	26.9	1.43	6.2	17.8			0.2	0.05
18832	48- 57	IIB32	27.4	1.55	6.2	15.7			0.3	0.06
18833	57- 65	IIC	21.8	1.91	6.9	12.3			0.3	0.09
				Toronto						
18834	0- 7	A1	18.3[e]	1.01	4.0[e]	23.0[e]			0.3	0.06
18835	7- 14	A2	21.5	1.05	3.3	17.7			0.3	0.05
18836	14- 17	A3	26.2	1.11	5.2	21.3			0.2	0.04
18837	17- 21	B1	33.3	0.93	7.6	25.2			0.1	0.03
18838	21- 28	B21	34.2	0.77	7.5	26.7			0.1	0.02
18839	28- 36	B22	29.7	0.93	7.6	24.2			0.1	0.03

[d]Data from Phillips (1958).
[e]Data from Bailey et al. (1964).

Table 6. (Continued)

									Calculated ratios	
Sample number	Depth (inches)	Horizon	<2μ clay %	Non-exch. Mg in <1μ fraction %	Exch. Mg++ in whole soil Me/ 100g	C.E.C. Me/ 100g	Exch. H+ Me/ 100g	Base saturation %	%Mg/ Me/ 100g Mg++	%Mg/ %<2μ clay
				Toronto (continued)						
18840	36- 45	IIB3	19.6	1.24	5.4	15.2			0.2	0.06
18841	45- 49	IIC1	22.2	2.04	6.0	11.2			0.3	0.09
18842	49- 61	IIC2	20.1	2.12	3.9	9.0			0.5	0.11
				Toronto						
18852	0- 8	A1	23.4[e]	1.05	2.8[e]	28.9[e]			0.4	0.04
18853	8- 14	A21	24.1	1.11	3.0	20.6			0.4	0.05
18854	14- 18	A22	28.5	1.13	4.4	22.8			0.3	0.04
18855	18- 22	B1	31.8	1.15	6.1	24.2			0.2	0.04
18856	22- 29	B21	33.5	1.17	6.3	25.6			0.2	0.03
18857	29- 36	IIB22	28.9	1.26	5.8	21.7			0.2	0.04
18858	36- 45	IIB3	23.8	1.37	5.7	16.6			0.2	0.06
18859	45- 51	IIC	16.3	2.23	6.7	8.1			0.3	0.14
				Xenia						
18843	0- 4	A1	18.3[e]	0.97	2.4[e]	25.4[e]			0.4	0.05
18844	4- 10	A2	17.4	1.08	2.1	15.3			0.5	0.06
18845	10- 14	A3	25.2	1.05	4.0	17.8			0.3	0.04
18846	14- 18	B1	28.3	1.11	5.7	20.2			0.2	0.04
18847	18- 28	B21	30.0	1.13	5.6	21.6			0.2	0.04
18848	28- 38	IIB22	25.8	1.09	4.3	17.9			0.3	0.04
18849	38- 48	IIB31	25.2	1.23	5.5	15.4			0.2	0.05
18850	48- 57	IIB32	24.2	1.80	6.9	13.0			0.3	0.07
18851	57- 70	IIC	20.7	2.12	5.1	8.6			0.4	0.10
				Russell (Ohio, WA-37)						
10124	0- 8	Ap	20.2[f]	0.94						0.05
10125	8- 13	A2	28.0	0.86						0.03
10126	13- 19	B1	36.7	0.85						0.02
10127	19- 25	B2	35.9	0.94						0.03
10128	25- 32	IIB3	38.5	1.18						0.03
10129	32- 38	IIC1	26.9	1.47						0.05
10130	38- 46	IIC2a	27.9	1.54						0.06
10131	46- 60	IIC2b	29.2	1.69						0.06

[f]Data from Ohio Agricultural Experiment Station (Ohio Agricultural Experiment Station Staff, 1958).

Table 6. (Continued)

Sample number	Depth (inches)	Horizon	<2μ clay %	Non-exch. Mg in <1μ fraction %	Exch. Mg++ in whole soil Me/100g	C.E.C. Me/100g	Exch. H+ Me/100g	Base saturation %	Calculated ratios: %Mg/Me/100g Mg++	Calculated ratios: %Mg/%<2μ clay
				Fincastle (PB-10)						
7129	0- 8	Ap	14.9[f]	0.92						0.06
7130	8- 11	A2	21.4	0.66						0.03
7131	11- 14	B1	29.6	0.63						0.02
7132	14- 19	B21	36.0	0.58						0.02
7133	19- 24	B22	34.8	0.77						0.02
7134	24- 28	B31	32.5	0.80						0.02
7135	28- 32	B32	30.1	0.87						0.03
7136	32- 36	B33	29.7	1.11						0.04
7137	36- 40	IIC1	26.9	1.17						0.04
7138	40- 47	IIC2	22.5	1.30						0.06
				Till-I						
I-1	30[g]	DU[h]	21.7	1.01						0.05
2	40[g]	UU[i]	24.1	1.01						0.04
3	50[g]	UU	21.9	1.11						0.05
4	100[g]	UU	12.2	1.01						0.08
				Till-II						
II-1	5[g]	OL[j]	26.0	0.97						0.03
2	20[g]	UU	21.4	1.00						0.05
3	30[g]	UU	20.4	1.13						0.06

[g]Feet below surface, approximately.
[h]DU = deoxidized, unleached till.
[i]UU = unoxidized, unleached till.
[j]OL = oxidized, leached till.

Figure 11. The somewhat poorly drained prairie/forest transition soil, P736, has a Mg content varying from 0.8 to 1.0 percent in the A horizon, from 0.8 to 0.9 percent in the upper B horizon and from 0.9 to 1.1 percent in the IIB and IIC horizons.

The profile distribution of Mg in the <1μ clay fraction of the eastern Iowa thin loess/till soils is shown in Figure 12 (Dinsdale, Klinger and Maxfield) and Figure 13 (Waubeek and P739). Of the prairie soils the better drained Dinsdale and Klinger soils have a Mg content varying from 0.9 to 1.0 percent in the A horizon, 0.9 to 1.1 percent in the upper B horizon and from 0.9 to 1.0 percent in the IIB and IIC horizons. The poorly drained soils range in Mg content from 0.8 to 1.1 percent in the A horizon, 0.9 to 1.2 percent in the upper B horizon and 0.8 to 1.0 percent in the IIB and IIC horizons. The Mg content in the better drained prairie/forest transition soils, Waubeek and Franklin ranges from 0.9 to 1.1 percent in the A horizon, from 0.8 to 1.0 percent in the upper B horizon and from 0.9 to 1.0 percent in the IIB and IIC horizons. In the well drained forested profile, P739, the Mg content ranges from 1.0 to 1.1 in the A horizon and upper B horizon and from 0.7 to 0.9 in the IIB and IIC horizons. Generally in the thin loess/till soils the Mg content of the eastern Iowa profiles is lower than that of the northwestern Iowa profiles, but the profile distribution is similar for the two areas. The profile distribution increases from A to upper B, and decreases in the IIB and IIC till material.

The profile distribution of Mg in the thick loess soils is given in Figure 14 for the prairie soils (Tama, Muscatine and Garwin) and in

Figure 11. Profile distribution of <2μ clay and magnesium in the <1μ clay in Sac II, P737 and P738; a prairie drainage sequence from northwestern Iowa

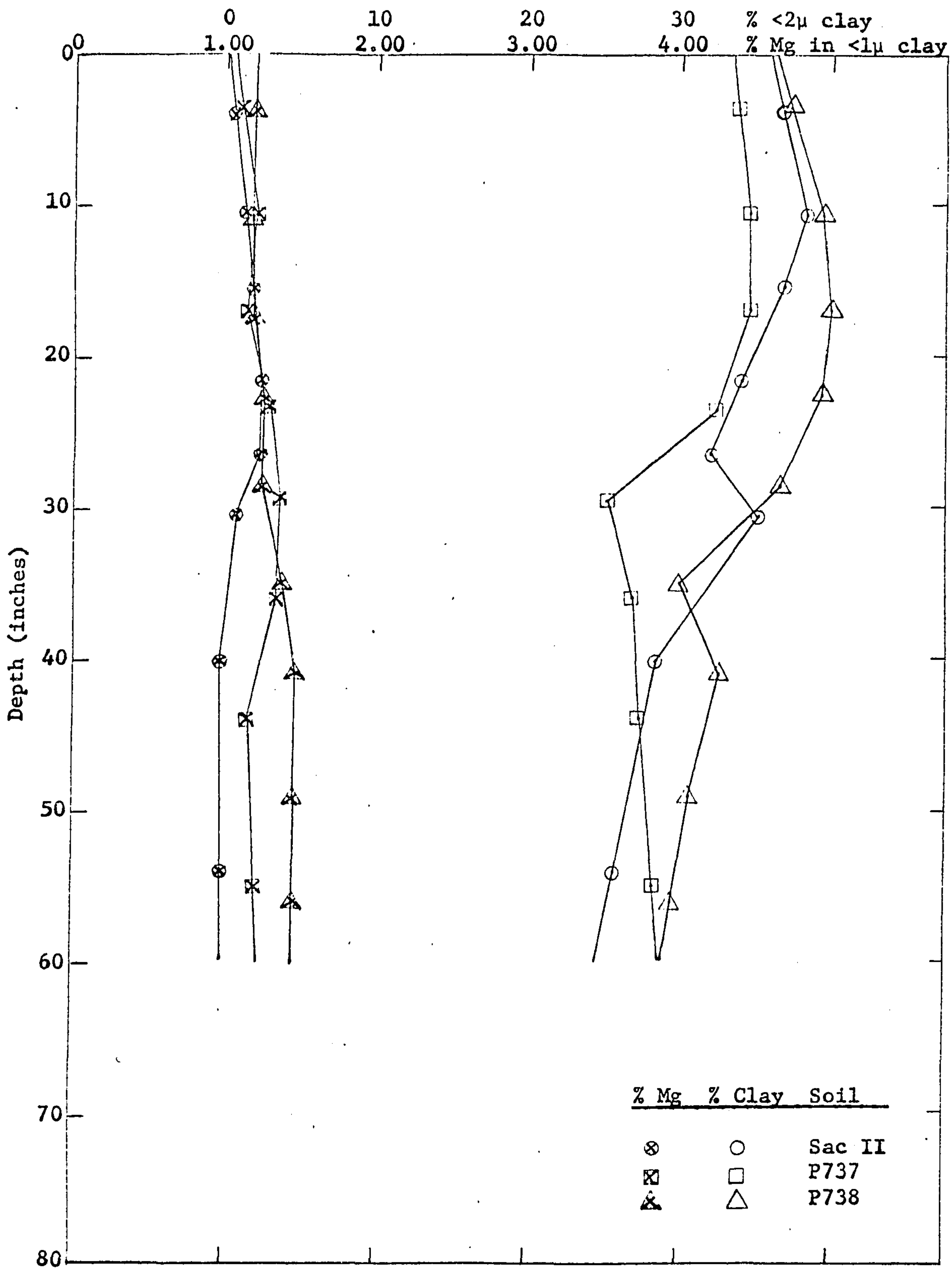

0 10 20 30 % <2μ clay
0 1.00 2.00 3.00 4.00 % Mg in <1μ clay
0
10
20
30
40
50
60
70
80
Depth (inches)
% Mg % Clay Soil
Sac II
P737
P738

Figure 12. Profile distribution of $<2\mu$ clay and magnesium in the $<1\mu$ clay in Dinsdale I, Klinger I and Maxfield I; a prairie drainage sequence from eastern Iowa

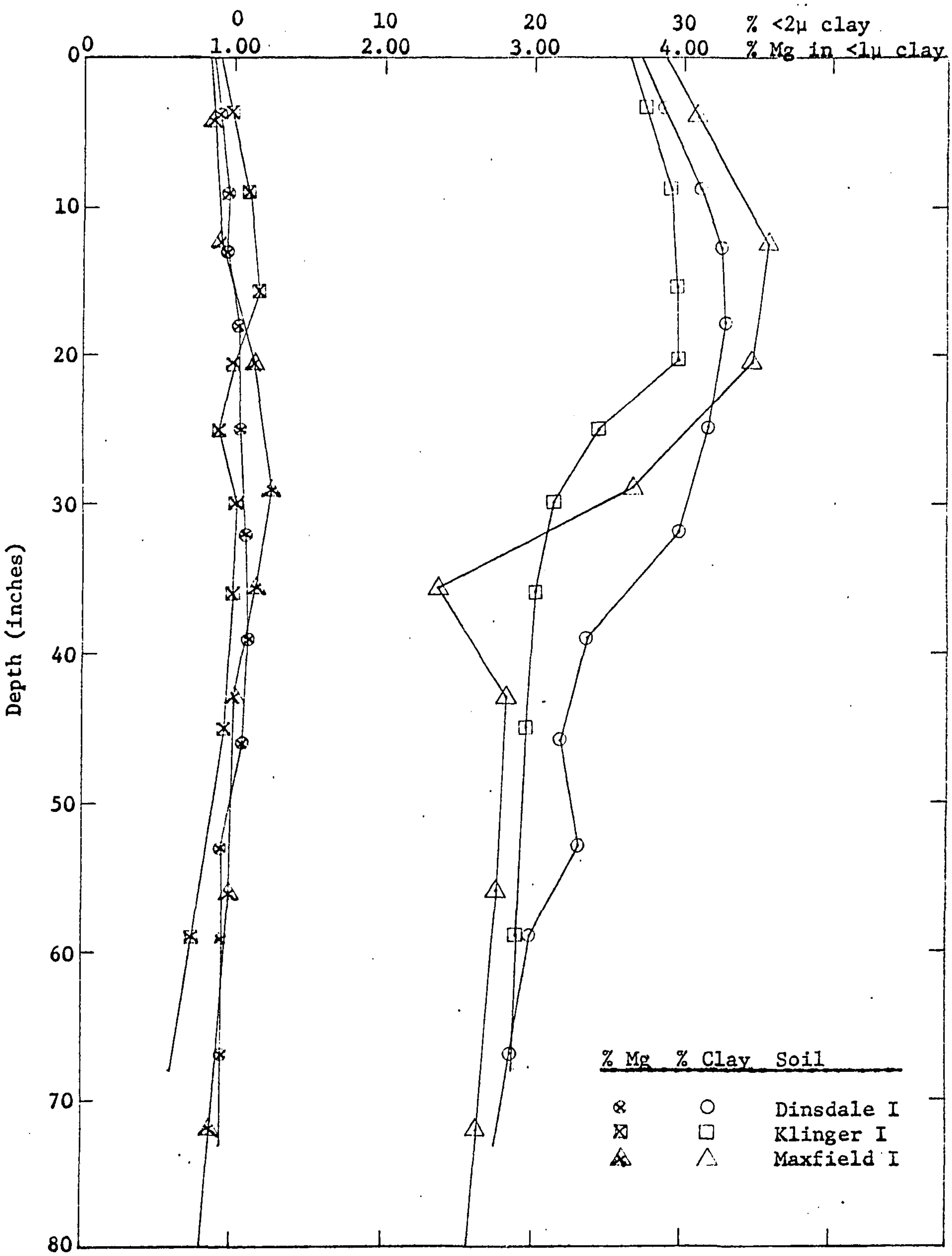
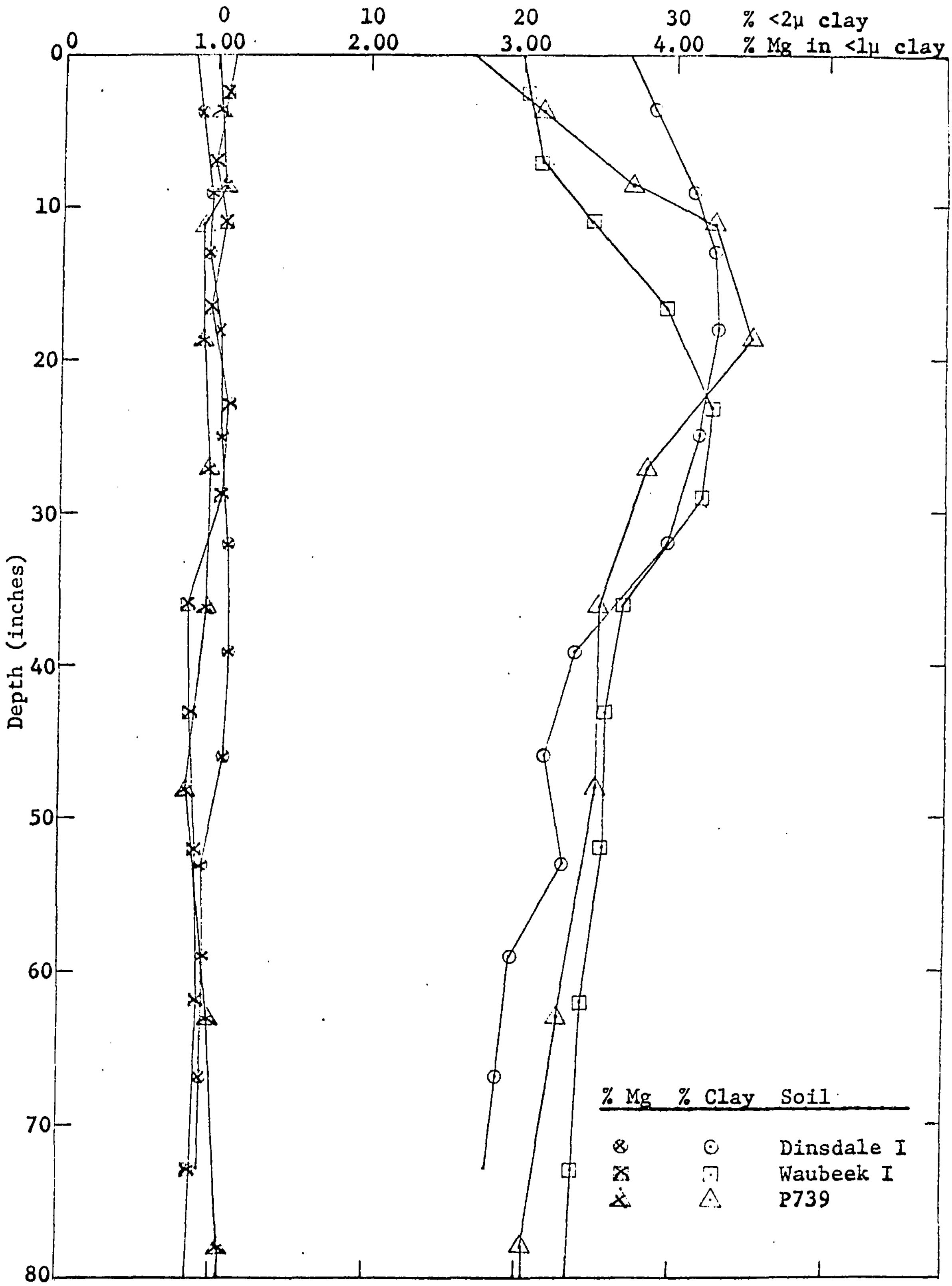

0
10
20
30
% <2μ clay
0
1.00
2.00
3.00
4.00
% Mg in <1μ clay
0
10
20
30
40
50
60
70
80
Depth (inches)
% Mg % Clay Soil
Dinsdale I
Klinger I
Maxfield I

Figure 13. Profile distribution of <2μ clay and magnesium in the <1μ clay in Dinsdale I, Waubeek I and P739; a well drained vegetation sequence from eastern Iowa



0
10
20
30
% <2μ clay
0
1.00
2.00
3.00
4.00
% Mg in <1μ clay
0
10
20
30
40
50
60
70
80
Depth (inches)
% Mg
% Clay
Soil
Dinsdale I
Waubeek I
P739

Figure 14. Profile distribution of $<2\mu$ clay and magnesium in the $<1\mu$ clay in Tama, Muscatine and Garwin soils; a prairie drainage sequence from eastern Iowa

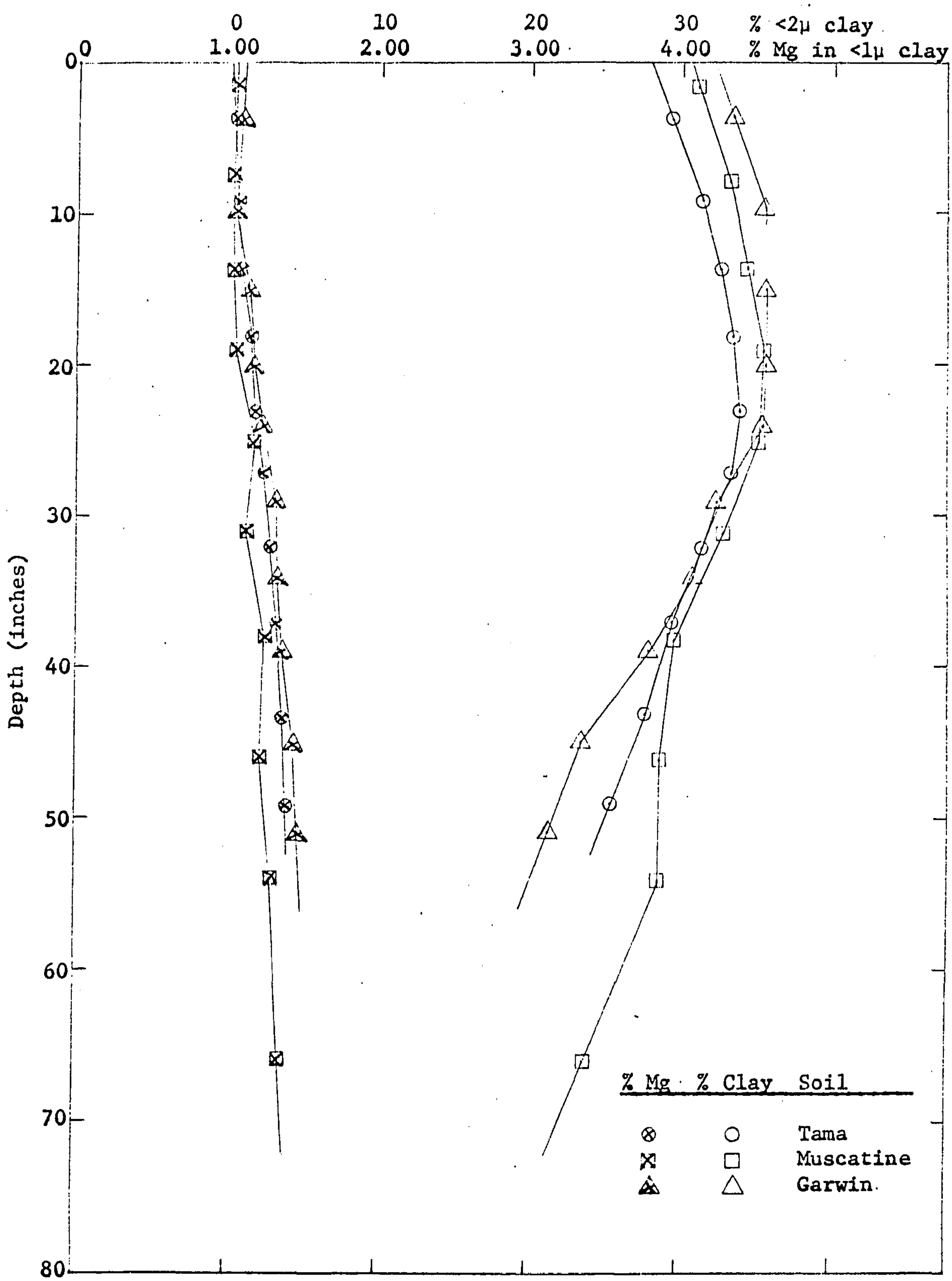
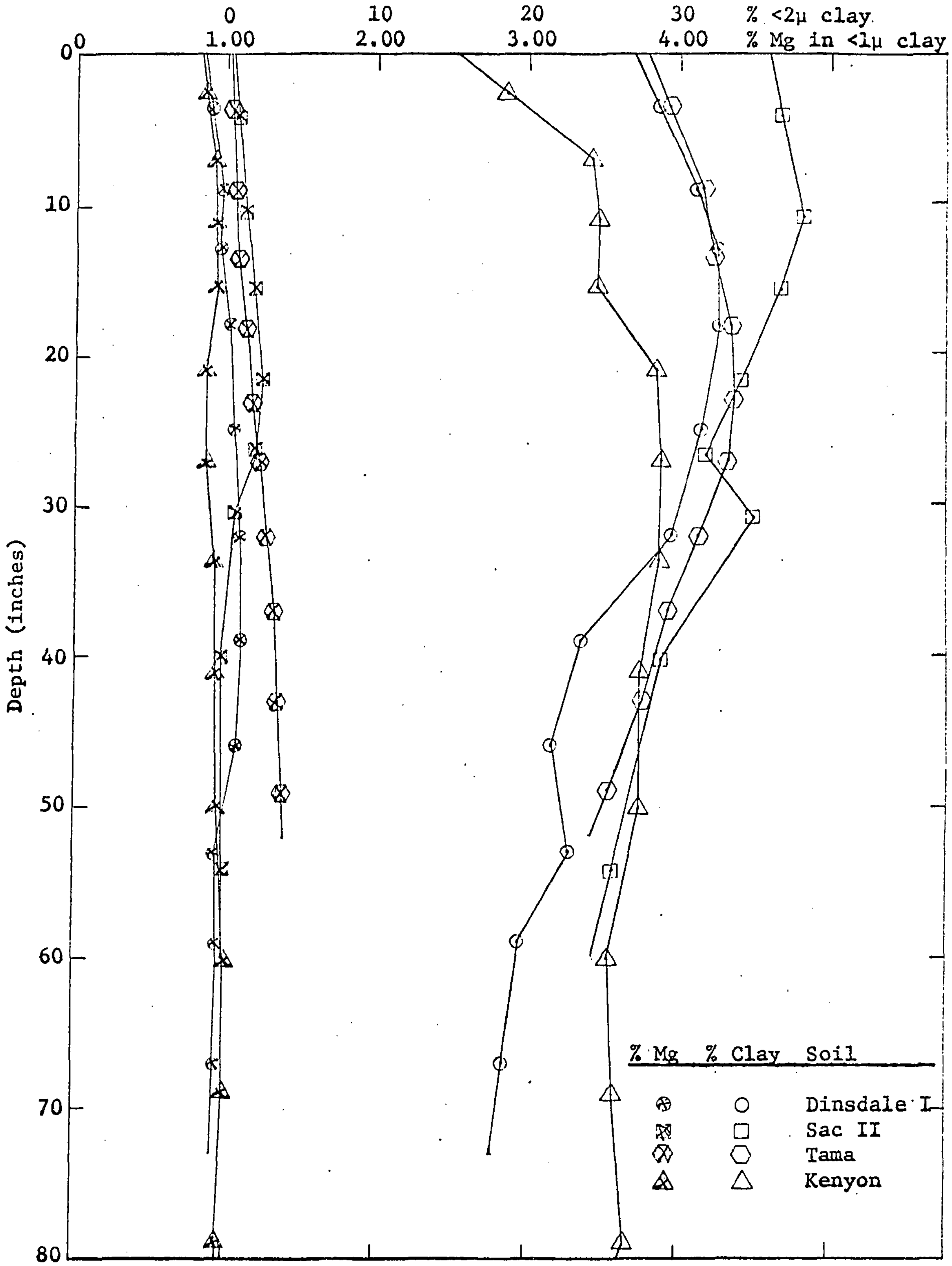

0 10 20 30 % <2μ clay
0 1.00 2.00 3.00 4.00 % Mg in <1μ clay
Depth (inches)
0
10
20
30
40
50
60
70
80
% Mg % Clay Soil
Tama
Muscatine
Garwin

Figure 17 for the forested soil (Fayette). The Mg in the prairie soils ranges from 1.0 to 1.1 percent in the A horizon, from 1.1 to 1.4 in the B horizon and from 1.2 to 1.5 percent in the C horizon. Drainage does not appear to have much effect on the Mg content of the thick loess prairie soils. The Mg content in the forested soils (Fayette, Stronghurst and Traer) ranges from 1.0 to 1.1 percent in the A horizon, from 0.9 to 1.1 percent in the B horizon and from 1.1 to 1.4 percent in the C horizon. The more developed, forested and prairie/forest transition soils have a slightly greater variation between the maximum and minimum Mg content in the profile than the prairie soils. The Mg content of the upper horizons of the thick loess soils is similar to the upper horizons of comparable thin loess/till soils of the same area, but the content of the lower C horizons of the thick loess soils is lower than in the lower C horizons of the thin loess/till soils.

The profile distribution of Mg in the surficial sediment soils is shown by the Kenyon profile in Figure 15 and by the Tripoli profile in Figure 16. The better drained, prairie soils, Kenyon and Readlyn, have a Mg content varying from 0.8 to 0.9 percent in the A horizon, from 0.9 to 1.0 percent in the B horizon and from 1.0 to 1.2 percent in the C horizon. The Mg content of the A horizon of the poorly drained, prairie soil, Tripoli, is slightly higher (0.8 to 1.1 percent) than in the Kenyon and Readlyn, but the contents in the B and C horizons are similar to the content of the B and C horizons of the other two soils. The Mg content of the upper horizons of the surficial sediment soils is lower than in the upper horizons of the thin loess/till soils, but the content of the

Figure 15. Profile distribution of $<2\mu$ clay and magnesium in the $<1\mu$ clay in Dinsdale I, Tama and Kenyon (eastern Iowa) and Sac II (northwestern Iowa); well drained prairie soils from different parent material



0
10
20
30
% <2μ clay
0
1.00
2.00
3.00
4.00
% Mg in <1μ clay
0
10
20
30
40
50
60
70
80
Depth (inches)
% Mg
% Clay
Soil
Dinsdale I
Sac II
Tama
Kenyon

Figure 16. Profile distribution of $<2\mu$ clay and magnesium in the $<1\mu$ clay in Maxfield I, Garwin and Tripoli (eastern Iowa) and P738 (northwestern Iowa); poorly drained prairie soils from different parent material

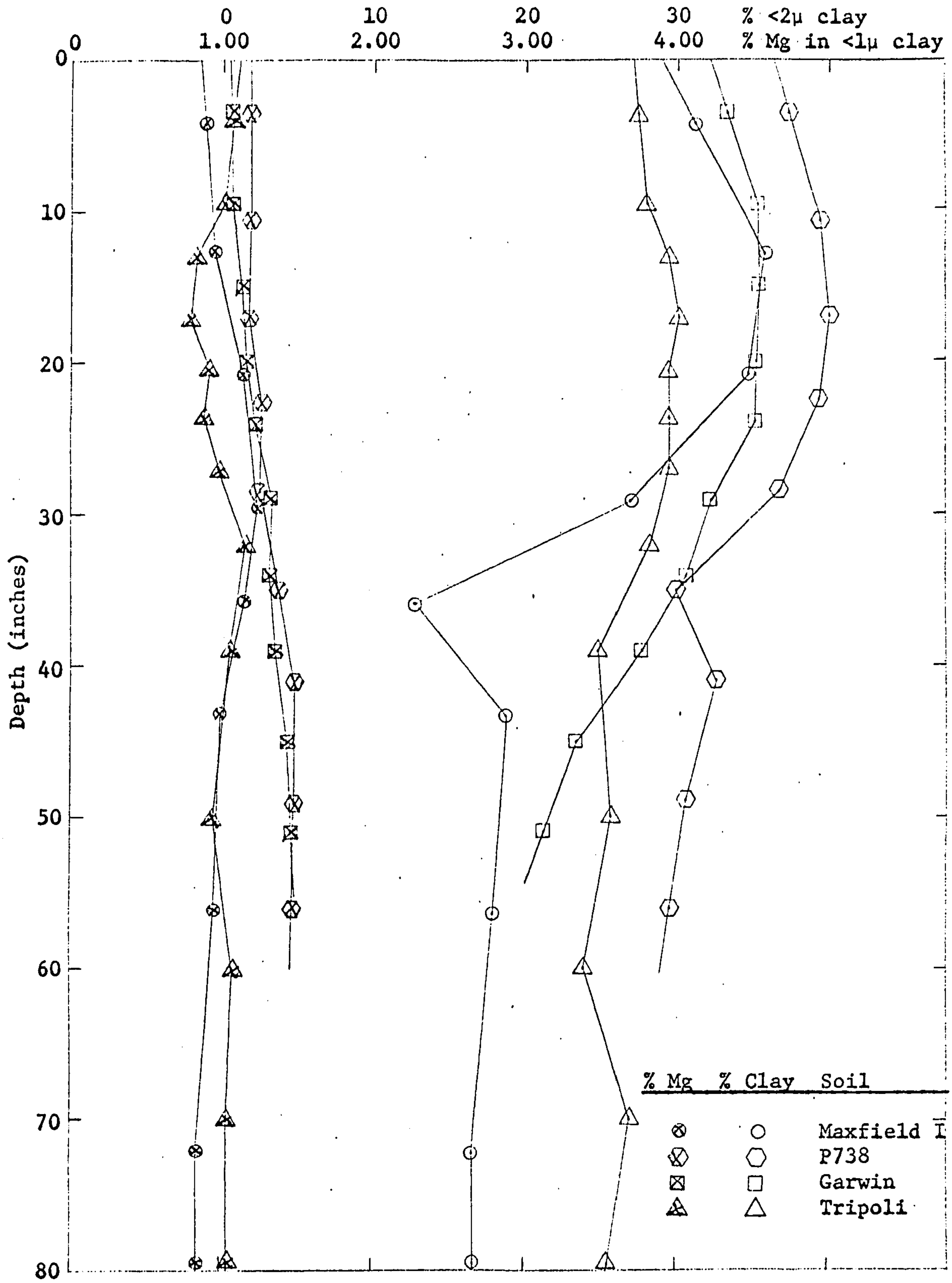
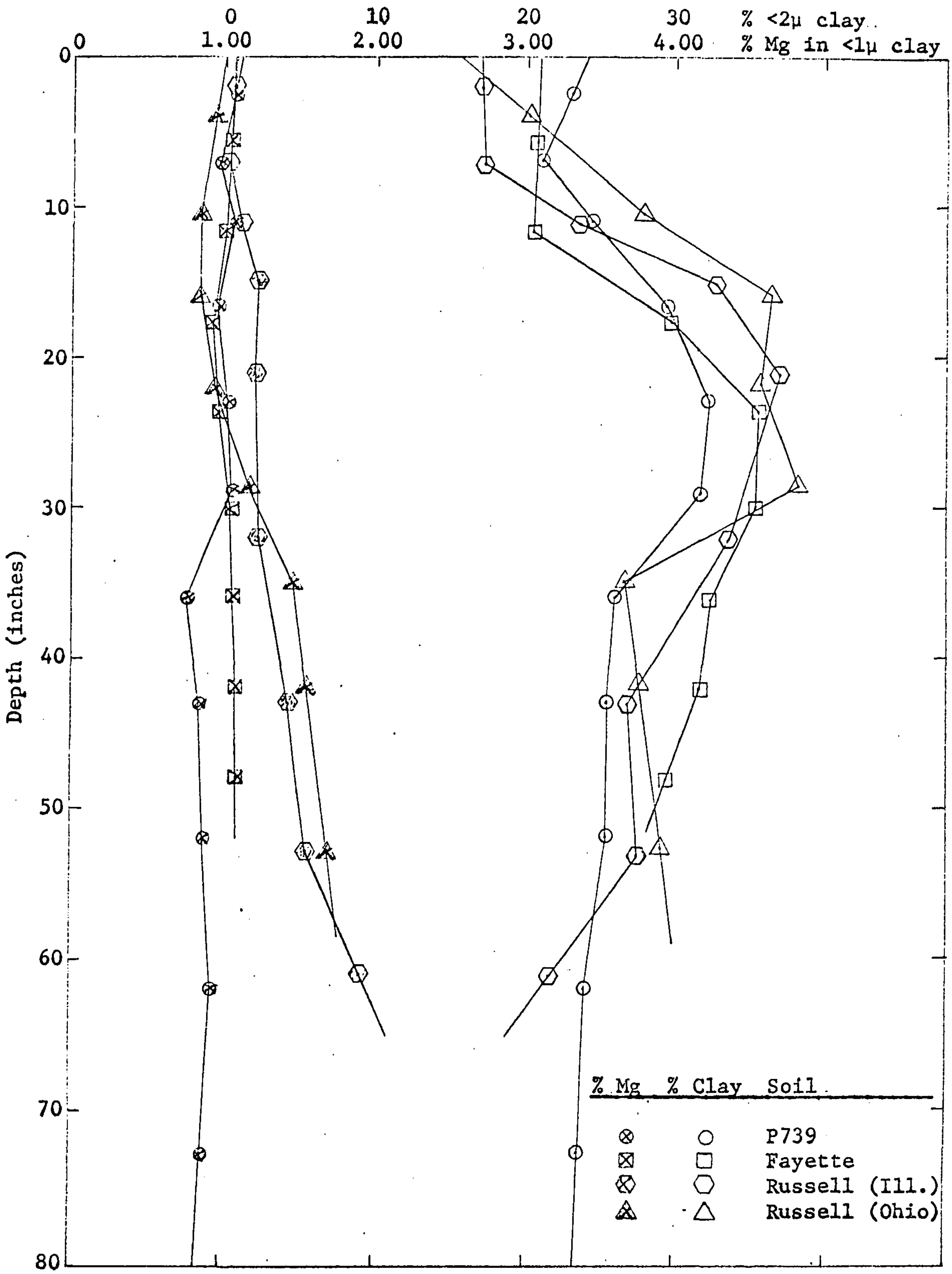

% <2μ clay
% Mg in <1μ clay
0
10
20
30
1.00
2.00
3.00
4.00
0
Depth (inches)
0
10
20
30
40
50
60
70
80
% Mg
% Clay
Soil
Maxfield I
P738
Garwin
Tripoli

Figure 17. Profile distribution of $<2\mu$ clay and magnesium in the $<1\mu$ clay in P739 and Fayette (eastern Iowa), Russell (Illinois) and Russell (Ohio); well drained, forested thin loess/till soils



0
10
20
30
% <2μ clay
0
1.00
2.00
3.00
4.00
% Mg in <1μ clay
Depth (inches)
0
10
20
30
40
50
60
70
80
% Mg
% Clay
Soil
P739
Fayette
Russell (Ill.)
Russell (Ohio)

till portion of the two groups of soils is similar.

The thin loess/till soils from Illinois and Ohio have a profile distribution of Mg as shown by the Russell profiles in Figure 17. The better drained, forested soils, Russell and Xenia, from Illinois have a Mg content varying from 1.0 to 1.1 percent in the A horizon, from 1.2 to 1.8 percent in the B horizon and from 1.9 to 2.1 percent in the C horizon. The Mg content of the somewhat poorly drained, prairie/forest transition soil, Toronto, is similar to the Russell soils except the Toronto B horizon is slightly lower. The Russell and Fincastle soils from Ohio have a Mg content of 0.7 to 0.9 percent in the A horizon, 0.6 to 1.1 percent in the B horizon and 1.5 to 1.7 percent in the C horizon. Generally in the thin loess/till soils the Illinois and Ohio profiles have a Mg content in the loess portion similar to the loess portion of the Iowa soils, but in the till portion the Illinois and Ohio soils have a higher content.

The Mg content of the $<1\mu$ clay fraction of the upper horizons generally decreases from west to east, and is in the order: northwestern Iowa > eastern Iowa > eastern Illinois > southwestern Ohio. This is in the order of increasing rainfall (Figures 1 and 2). However, there are differences within each area due to other environmental factors such as parent materials, drainage and vegetation. There is not a large relative difference in the Mg content, nor a large variation in the profile, but a very small difference is significant because the values are so small on a percentage basis, and they are generally consistent.

Generally the profile distribution of Mg in the $<1\mu$ clay fraction appears to be unrelated to the profile distribution of <2μ clay or soil textural development as indicated in Figures 11-17. All of the soils except the northwestern Iowa profiles show various amounts of clay accumulation in the B horizon, but the Mg tends to increase gradually with depth. Even the soils with high development such as Fayette and Russell (Figure 17) do not have a lower Mg content in the B horizon than in A horizon; although these soils have the greatest difference between maximum and minimum Mg in the profiles of the soils studied.

The Mg content of the <1μ clay fraction of the Iowa soils appears to be more related to the physical and chemical weathering that the sediments have undergone, both before and after deposition, than to the composition of the materials (Figures 15 and 16). The Mg content of the loess portion of the thin loess/till soils is similar to the upper horizons of the thick loess soils of the same area. The lower till horizons of the thin loess/till soils have a Mg content similar to the till portion of the surficial sediment soils (Kenyon sequence), but higher than the content of the lower loess portion of the thick loess soils. The Mg content of the lower till horizons of the Iowa thin loess/till soils is less than the lower horizons of the Illinois and Ohio thin loess/till soils (Figure 17).

The better drained soils have a higher Mg content in the solum than the poorer drained associates, but the lower horizons do not vary much with drainage. In order of increasingly poorer drainage the Mg content is in the order: Dinsdale > Klinger > Maxfield in eastern Iowa and Sac > P737 > P738 in northwestern Iowa (Figures 11 and 12).

Vegetation does not appear to have any effect on the Mg content of the <1μ clay fraction of these soils; although, it may indirectly affect the upper two or three horizons of the forested soils because of the increased leaching. A comparison of the Mg distribution of a vegetation sequence is shown in Figure 13, and a comparison of Iowa to Illinois and Ohio forested soils is shown in Figure 17.

Sodium Tetraphenylboron Extractable Potassium

Sodium tetraphenylboron, NaTPB, extractable potassium was determined for selected soils and the data are given in Table 7. The determinations were made on whole soil and the periods of extraction were 7 and 60 days. The nonexchangeable potassium, K, and calculated values of grams K released/100g <2μ clay, percent of nonexchangeable K content released in 7 days and the 60 day to 7 day K release ratio are also given in Table 7.

A comparison of the K released by the prairie thin loess/till soils from northwestern and eastern Iowa is shown in Figure 18 (7 day period) and Figure 19 (60 day period). Of the well drained soils the northwestern Iowa Sac released 4180 to 5340 ppm K in a 7 day period and 5600 to 5950 ppm in a 60 day period, and the eastern Iowa Dinsdale released 3190 to 3750 ppm in 7 days and 3940 to 5000 ppm in 60 days. Of the poorly drained soils the P738 released 2970 to 3175 ppm K in 7 days and 3480 to 4400 ppm in 60 days and the Maxfield released 2540 to 3065 ppm in 7 days and 3150 to 4355 ppm in 60 days. The well drained forested soil

Table 7. Sodium tetraphenylboron extractable potassium and related data for selected soils

Sample number	Depth (inches)	Horizon	<2μ clay %	K released in 7 days ppm	Grams K released/ 100g clay	% of K released in 7 days	%K x %<2μ clay	K released in 60 days ppm	60 day/ 7 day K release ratio
				Sac (P746)					
P746-2	7- 11	A3	38.4	4180	1.09	69	61.1	5600	1.34
4	18- 25	B21	33.6	4900	1.46	93	52.8	5950	1.21
6	28- 33	IIB23	32.0	5340	1.67	98	54.7	5760	1.08
8	44- 57	IICca	34.4	4630	1.35	69	67.1	5770	1.25
				P737 (Unnamed soil no. 282)					
P737-2	7- 14	A3	34.8	3555	1.02	69	51.5	5140	1.45
4	20- 27	B21	32.6	3970	1.22	86	46.3	5380	1.36
6	32- 40	IIB23	27.0	2720	1.01	51	53.7	3520	1.29
8	49- 60	IICca	28.4	3125	1.10	50	62.5	3590	1.15
				P738 (Unnamed soil no. 191)					
P738-2	7- 14	A12	39.4	3175	0.81	58	55.2	4400	1.39
4	20- 25	B1	39.2	3750	0.96	72	52.5	3960	1.06
6	32- 38	IIB3	30.0	2970	0.99	55	54.0	3770	1.27
8	45- 52	IIC2	30.6	2975	0.97	60	49.6	3480	1.17
				Dinsdale (P704)					
P704-2	7- 11	A12	31.2	3470	1.11	78	44.6	4520	1.30
4	15- 21	B1	32.9	3750	1.14	89	42.1	5000	1.33
8	43- 50	IIB33	21.7	3490	1.61	83	42.1	4300	1.23
10	56- 62	IIC2	19.5	3190	1.64	75	42.7	3940	1.24
				Klinger (P707)					
P707-2	9- 13	A3	28.1	2820	1.00	63	44.4	3740	1.33
4	19- 26	B21	30.6	3040	0.99	77	39.5	3940	1.30
7	36- 40	IIB32	25.6	3590	1.40	93	38.4	4300	1.20
9	46- 52	IIC1	27.9	3540	1.27	84	42.1	5000	1.41
				Maxfield (P733)					
P733-2	8- 17	A12	35.8	2810	0.78	62	45.1	3630	1.29
4	24- 34	B2g	26.9	3065	1.14	85	36.1	4355	1.42
7	48- 64	IIC1	17.7	2625	1.48	81	32.2	3170	1.21
9	80- 97	IIC2	16.5	2540	1.54	81	31.2	3150	1.24

Table 7. (Continued)

Sample number	Depth (inches)	Horizon	<2μ clay %	K released in 7 days ppm	Grams K released/ 100g clay	% of K released in 7 days	%K x %<2μ clay	K released in 60 days ppm	60 day/ 7 day K release ratio
			P739 (Unnamed soil no. 481)						
P739-3	9- 13	A22	24.5	2900	1.18	61	47.0	4230	1.46
5	20- 26	B21	32.2	3575	1.11	80	44.4	4870	1.36
8	39- 47	IIB3	25.4	3115	1.23	74	42.2	3960	1.27
10	57- 68	IIC2	24.0	3195	1.33	78	40.8	3980	1.25
			Russell (Ill.)						
18826	4- 9	A2	17.0	2760	1.62	73	37.9	4300	1.56
18828	13- 17	B1	32.6	5030	1.54	74	67.5	6470	1.19
18831	38- 48	IIB31	26.9	5510	2.05	83	66.7	6930	1.26
18833	57- 65	IIC	21.8	5570	2.56	80	70.2	6300	1.13
			Maxfield (P734, unoxidized, unleached till)						
P734-15	131-148	IIC6	25.3	3750	1.48	93	40.2	4880	1.30
17	172-184	IIC7	26.3	3585	1.36	83	43.1	4920	1.37

Figure 18. Potassium released from whole soil with NaTPB in 7 day period from Dinsdale I and Maxfield I, well and poorly drained soils from eastern Iowa and Sac I and P738, well and poorly drained soils from northwestern Iowa

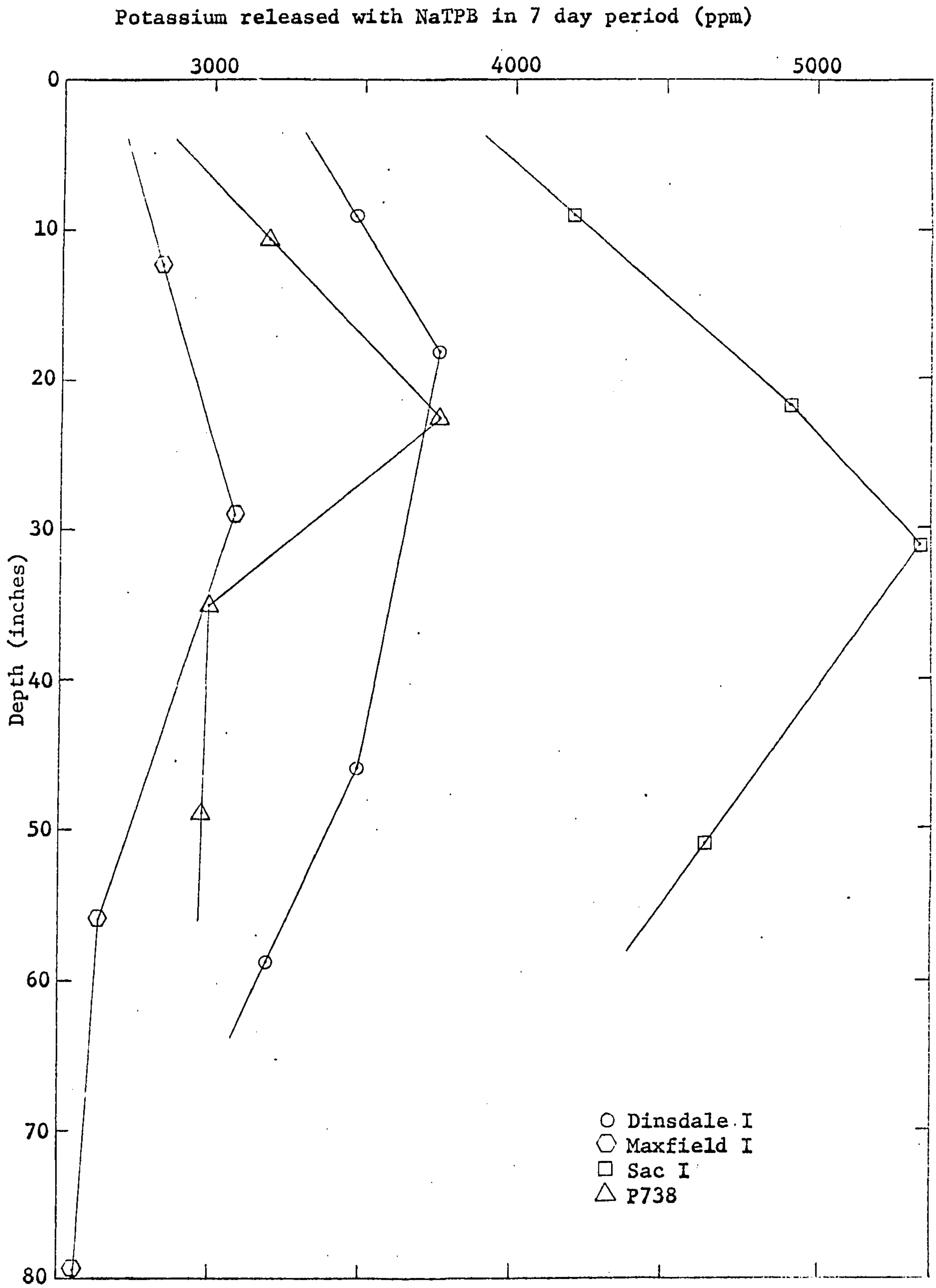
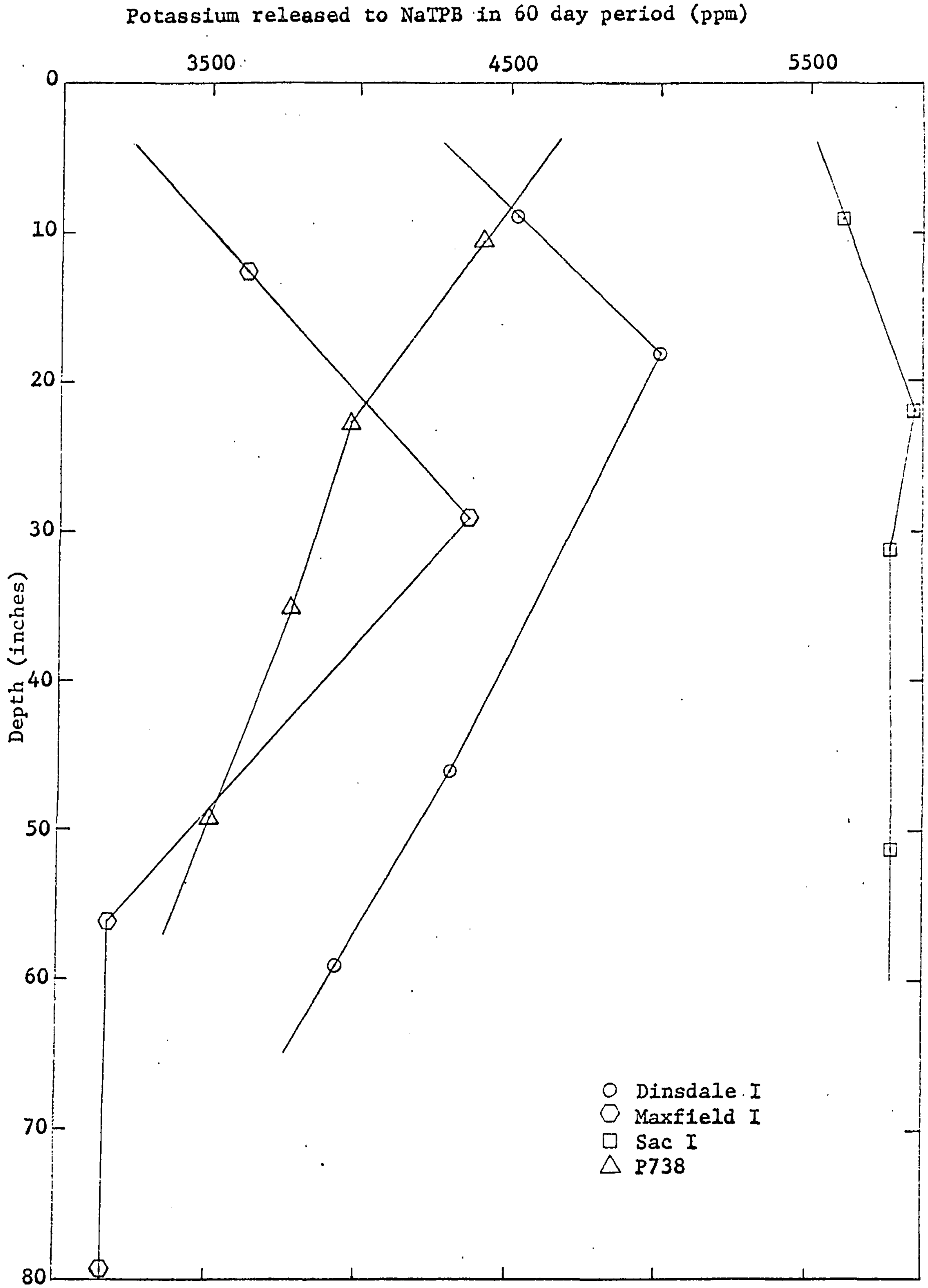

Potassium released with NaTPB in 7 day period (ppm)
3000
4000
5000
0
10
20
30
40
50
60
70
80
Depth (inches)
Dinsdale I
Maxfield I
Sac I
P738

Figure 19. Potassium released from whole soil with NaTPB in 60 day period from Dinsdale I and Maxfield I, well and poorly drained soils from eastern Iowa, and Sac I and P738 well and poorly drained soils from northwestern Iowa


Potassium released to NaTPB in 60 day period (ppm)
3500
4500
5500
0
10
20
30
40
50
60
70
80
Depth (inches)
Dinsdale I
Maxfield I
Sac I
P738

from eastern Iowa, P739, released 2900 to 3575 ppm in 7 days and 3960 to 4870 ppm in 60 days. The upper horizon of the well drained, forested Russell soil from Illinois released 2760 ppm in 7 days and 4300 ppm in 60 days, but the lower horizons released 5030 to 5570 ppm in 7 days and 6300 to 6930 ppm in 60 days. Two lower till (11 to 15 feet below the surface) samples released approximately 3600 ppm in 7 days and 4900 in 60 days.

The northwestern Iowa soils released more K in both the 7 and 60 day periods than comparable eastern Iowa soils as shown by Figures 18 and 19. The poorly drained soils released less K than the better drained associated sequence soils. In the Iowa thin loess/till soils the K release is approximately the same in the loess and till portions of the profile; although soils with a high K content also release more K. Vegetation apparently does not noticeably affect the K release since the Dinsdale (prairie) and P739 (forested) show a similar K release (Table 7). The Russell soil from Illinois has a release similar to P739 profile (eastern Iowa) in the upper horizon, but the lower horizons have a much higher release than the P739 profile.

The 7 day and 60 day K release was also determined for individual horizons from several southeastern Iowa soils otherwise not included in this study to compare soils with a wider range of soil development. Soils with maximal and minimal clay development were selected to embrace the soils of this study and extend the range of textural development. The results for these samples are given in Table 8 along with other related data and references. The horizon of clay maximum from the highly

Table 8. Sodium tetraphenylboron extractable potassium and related data for selected clay maximum and minimum horizons and two reference samples

Sample number	Depth (inches)	Horizon	$<2\mu$ clay %	K released in 7 days ppm	Grams K released/ 100g clay	% of total K released	K released in 60 days ppm	60 day/ 7 day K release ratio	Nonexch. K in $<1\mu$ clay %	B/A horizon clay ratio
P16-6	20-24	B2	52.4[a]	4320	0.82	78	5815	1.35	1.05[b]	2.49
P186-4	17-22	B2	60.3[c]	3810	0.63	68	4660	1.22	0.93[b]	4.37
P421-6	19-22	B2	52.3[d]	4960	0.95	93	6120	1.24	1.02[b]	3.04
P423-6	17-22	B2	50.3[d]	4840	0.96	84	6720	1.39	1.14[b]	3.57
P424-4	15-21	B2	64.2[d]	4630	0.72	76	5475	1.18	0.95[b]	3.59
P424-5	21-31	B2	56.0[d]	4635	0.83		5800	1.25		3.13
P760-2	7-11	A12	33.0[e]	4160	1.26		5170	1.24		1.15
P700-3	10-14	A3	24.0[e]	1860	0.78		2940[f]	1.58		1.32
P701-3	9-13	A3	24.6[e]	1850	0.75	54	3090[f]	1.67	1.38	1.34
Grundite illite				21,350			2,238,000	105.00		
Belle Fouche montmorillonite				1020			1050	1.03		

[a]Data from Ulrich (1949) for prairie planosol Edina.
[b]Data from Protz (1965).
[c]Data from Godfrey (1951) for prairie planosol Putnam.
[d]Data from Cain (1956) for forested planosols.
[e]Data from Lincoln Soil Survey Laboratory (U.S. Soil Survey Staff, 1966).
[f]Data from Wells (1963).

developed soils and the horizon near the surface from the weakly developed soils were analyzed. The soils with maximal development have a low K content, but the K release was high (approximately 3800 to 4900 ppm in 7 days and 5800 to 6700 ppm in 60 days). The soils with minimal development released from 1850 to 4160 ppm K in 7 days, and only one sample was analyzed for 60 days which released 5170 ppm K. A sample of South Dakota bentonite, which has a very low K content, released 1020 ppm K in 7 days and 1050 ppm K in 60 days.

The clay maximum horizons from these highly developed soils from southeastern Iowa have the lowest K content in the profile, but released approximately as much K as the relatively undeveloped Sac and associated soils from northwestern Iowa that have a high K content. The minimum clay horizons of the weakly developed P700 and P701 profiles have a low (1850 ppm) release, but the 60 day to 7 day K release ratio is high, approximately 1.6.

Clay Mineralogy

Representative profiles and selected horizons from other profiles were analyzed by means of x-ray diffraction to determine the kind and relative amounts of clay minerals present. The results are given in Table 9, and the x-ray diffraction patterns are included in Appendix B. Identification of the clay minerals was made and the relative intensities were determined according to techniques described on page 42. The peak area (0.01 sq. in.) is used as a measure of the intensity of each clay

Table 9. X-ray diffraction data for selected soils

Sample number	Depth (inches)	Horizon	Peak area (0.01 sq.in.)[a] K	I	M	Calculated ratios M/K	M/I	M/<2μ clay
			Sac (P746)					
P746-1	0- 7	Alp	5	6	108	21.6	18.0	2.9
2	7- 11	A3	5	6	157	31.4	26.2	4.1
3	11- 18	B1	4	4	268	67.0	67.0	7.2
4	18- 25	B21	5	5	315	63.0	63.0	9.4
5	25- 28	IIB22	6	5	305	50.8	61.0	9.6
6	28- 33	IIB23	6	6	177	29.5	29.5	5.5
7	33- 44	IIB3ca	18	12	180	10.0	15.0	5.3
8	44- 57	IICca	17	10	129	7.6	12.9	3.8
			Sac (P747)					
P747-1	0- 8	Alp	6	7	139	23.1	19.8	3.8
2	8- 13	A3	7	7	164	23.4	23.4	4.3
3	13- 18	B1	7	5	192	27.4	38.4	5.1
4	18- 25	B21	7	5	238	34.0	47.6	7.0
5	25- 28	IIB22	11	8	249	22.6	31.1	7.9
6	28- 33	IIB23	12	9	197	16.4	21.8	5.5
7	33- 47	IIB3ca	10	9	121	12.1	13.4	4.3
8	47- 60	IICca	10	10	130	13.0	13.0	5.1
			P738 (Unnamed soil no. 191)					
P738-2	7- 14	A12	6	9	452	75.3	50.2	11.5
4	20- 25	B1	3	14	263	87.7	18.8	6.7
6	32- 38	IIB3	5	21	120	24.0	5.7	4.0
8	45- 52	IIC2	6	27	108	18.0	4.0	3.5
			Dinsdale (P704)					
P704-1	0- 7	Alp	10	8	77	7.7	9.6	2.7
2	7- 11	A12	8	7	96	12.0	13.7	3.1
3	11- 15	A3	8	6	128	16.0	21.3	3.9
4	15- 21	B1	10	6	245	24.5	40.8	7.5
5	21- 29	B2	8	4	235	29.4	58.8	7.4
6	29- 36	B31	9	4	311	34.6	77.7	10.5
7	36- 43	IIB32	11	6	110	10.0	18.3	4.7
8	43- 50	IIB33	22	10	136	6.2	13.6	6.3
9	50- 56	IIC1	23	12	125	5.4	10.4	5.4
10	56- 62	IIC2	27	14	120	4.5	8.6	6.2
11	62- 73	IIC3	26	14	103	4.0	7.4	5.5

[a]The peak area was measured by counting the squares (0.01 sq.in.) under each peak. (K=kaolinite, I=illite and M=montmorillonite).

Table 9. (Continued)

Sample number	Depth (inches)	Horizon	Peak area (0.01 sq.in.)[a] K	I	M	Calculated ratios M/K	M/I	M/<2μ clay
			Dinsdale (P705)					
P705-1	0- 6	A1p	6	4	66	11.0	16.5	2.3
2	6- 12	A3	7	4	109	15.5	27.2	3.3
3	12- 16	B1	9	5	210	23.3	42.0	6.3
4	16- 21	B21	14	5	349	24.9	69.8	10.6
5	21- 26	B22	11	4	242	22.0	60.5	8.3
6	26- 30	B23	13	6	265	20.2	4.4	11.1
7	30- 37	IIB31	14	12	177	12.6	14.8	7.9
8	37- 44	IIB32	15	14	235	15.7	16.8	9.3
9	44- 48	IIB33	14	13	214	15.3	15.3	9.4
10	48- 58	IIC1	14	13	167	11.9	12.8	8.0
11	58- 66	IIC2	14	13	173	12.4	13.3	8.3
			Klinger (P707)					
P707-1	0- 9	A1	5	3	102	20.4	34.0	3.5
2	9- 13	A3	6	4	173	28.8	43.3	6.2
3	13- 19	B1	8	5	314	39.2	62.8	10.1
4	19- 26	B21	12	7	356	29.7	50.8	11.6
5	26- 31	B22	12	7	389	32.4	55.6	14.5
6	31- 36	IIB31	40	12	171	4.3	14.3	8.2
7	36- 40	IIB32	44	12	218	5.0	18.2	8.5
8	40- 46	IIB33	42	13	207	4.9	15.9	7.4
9	46- 52	IIC1	48	14	179	3.7	12.8	6.4
10	52- 64	IIC2	46	15	182	4.0	12.1	6.8
			Maxfield (P733)					
P733-1	0- 8	A1p	5	4	325	65.0	81.3	10.5
2	8- 17	A12	7	6	365	52.1	60.8	10.2
3	17- 24	A3	4	4	359	89.8	89.8	10.4
4	24- 34	B2g	5	5	404	80.8	80.8	15.0
5	34- 37	IIB31	9	5	155	17.2	31.0	12.5
6	37- 48	IIB32	15	6	113	7.5	18.8	6.1
7	48- 64	IIC1	14	9	151	10.8	16.8	8.5
8	64- 80	IIC2	18	11	161	8.9	14.6	9.9
9	80- 97	IIC2	18	14	165	9.2	11.8	10.0
10	97-106	IIC3	14	17	151	10.8	8.9	6.5

Table 9. (Continued)

Sample number	Depth (inches)	Horizon	Peak area (0.01 sq.in.)[a] K	I	M	Calculated ratios M/K	M/I	M/<2μ clay
			P739 (Unnamed soil no. 481)					
P739-2	5- 9	A21	11	2	36	3.3	18.0	1.2
3	9- 13	A22	20	2	67	3.4	33.5	2.7
5	20- 26	B21	15	11	126	8.4	11.5	3.9
6	26- 33	B22	7	11	239	3.4	21.7	7.5
8	39- 47	IIB3	18	13	195	10.8	15.0	7.7
10	57- 68	IIC2	13	14	142	10.9	10.1	5.9
			Russell (Ill.)					
18826	4- 9	A2	13	2	43	3.3	21.5	2.5
18828	13- 17	B1	15	2	97	6.5	48.5	3.0
18829	17- 25	B21	7	6	195	27.8	32.5	5.3
18831	38- 48	IIB31	3	14	97	32.3	6.9	3.2
18833	57- 65	IIC	3	21	96	32.0	4.6	4.4
			Russell (Ohio, WA-37)					
10125		A2	8	4	77	9.6	19.3	2.7
10127		B2	19	6	93	4.9	15.5	2.6
10129		IIC1	2	27	12	6.0	0.4	0.5
10131		IIC2b	2	41	15	7.5	0.4	0.5
			Tama (Pal-1)					
Pal-1-1	0- 7	Ap	4	3	87	21.7	29.0	1.8
3	11- 16	A3	5	3	181	36.2	60.3	4.0
5	21- 25	B21	3	4	251	83.7	62.7	6.1
7	29- 34	B23	4	3	307	76.8	102.3	7.8
9	40- 46	B32	5	4	394	78.8	98.5	10.3
			Kenyon (P701)					
P701-2	5- 9	A1p2	6	1	47	7.8	47.0	1.9
3	9- 13	A3	13	1	68	5.2	68.0	2.8
5	18- 24	IIB2	15	3	160	10.7	5.3	5.6
7	30- 37	IIB23	15	7	169	11.3	24.1	5.9
9	45- 55	IIB32	19	13	187	9.8	14.4	6.9

Table 9. (Continued)

Sample number	Depth (inches)	Horizon	Peak area (0.01 sq.in.)[a] K	I	M	Calculated ratios M/K	M/I	M/<2μ clay
			Maxfield (P734, lower till)					
P734-15	131-148	IIC6	21	16	124	5.9	7.8	4.9
17	172-184	IIC7	21	15	128	6.1	8.5	4.9
			Till-I					
Till-I-1	30[b]	DU[c]	12	18	126	10.5	7.0	5.8
2	40	UU[d]	14	18	119	8.5	6.6	4.9
3	50	UU	13	21	127	9.8	6.1	5.8
4	100	UU	14	29	131	9.4	4.5	10.7

[b]Feet below surface, approximately.

[c]DU=deoxidized, unleached till.

[d]UU=unoxidized, unleached till.

mineral. This analysis is intended to determine the intensities of each clay mineral relative to others in the same sample and relative to other samples rather than a quantitative determination of the amount of each clay mineral present.

The montmorillonite and illite intensities (peak areas) for the thin loess/till profiles, Sac (northwestern Iowa) and Dinsdale (eastern Iowa), are shown in Figures 20 and 21. Generally the montmorillonite intensity in the well drained prairie soils increases with depth in the loess portion of the profile, decreases abruptly in the loess-till contact horizon, then increases slightly and becomes uniform to decreasing in the lower till horizons. The montmorillonite in the Dinsdale I profile increases

Figure 20. Profile distribution of montmorillonite and Illite peak areas (0.01 sq.in.) and <2μ clay in Sac I, a well drained prairie soil from northwestern Iowa

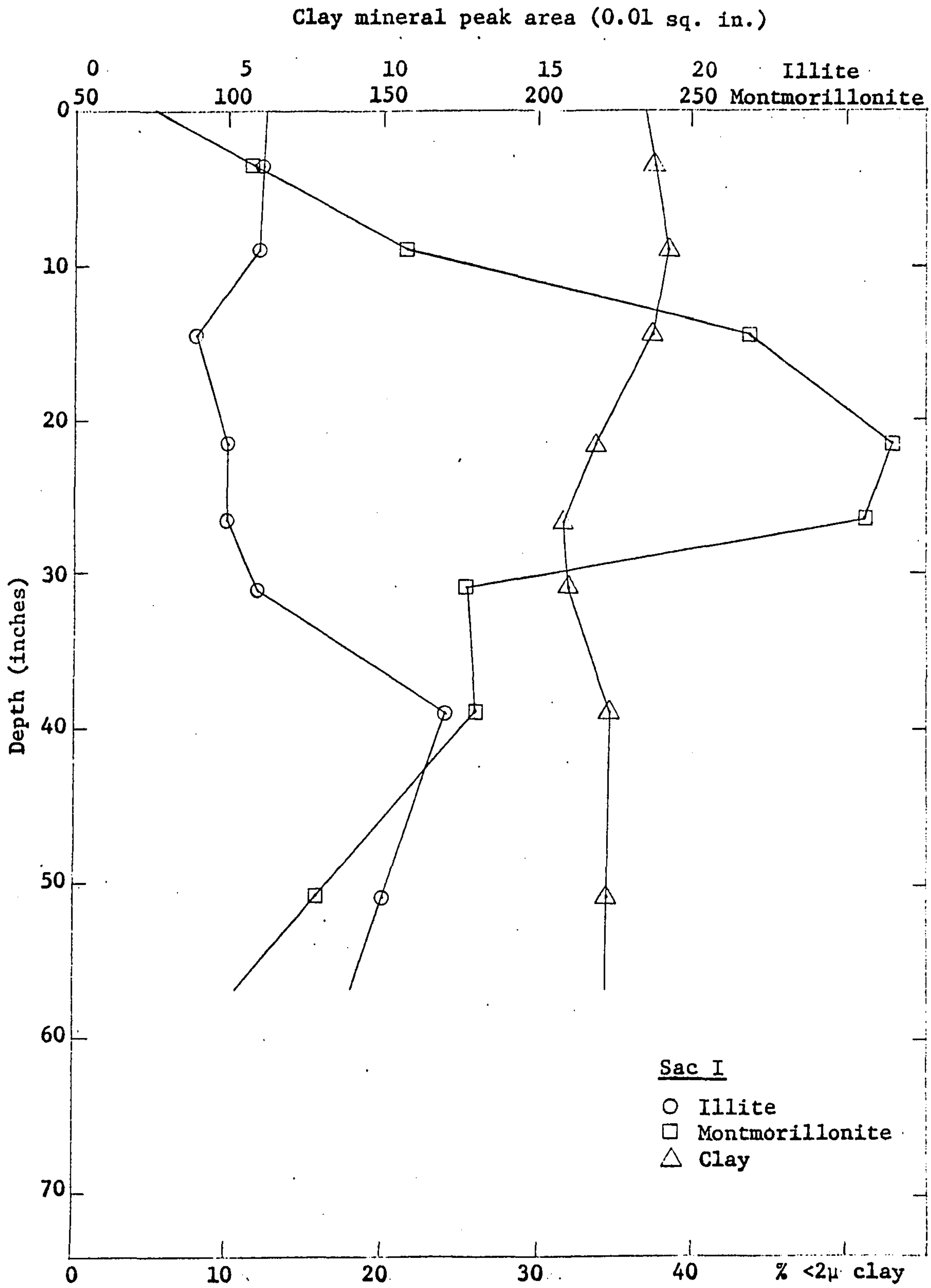
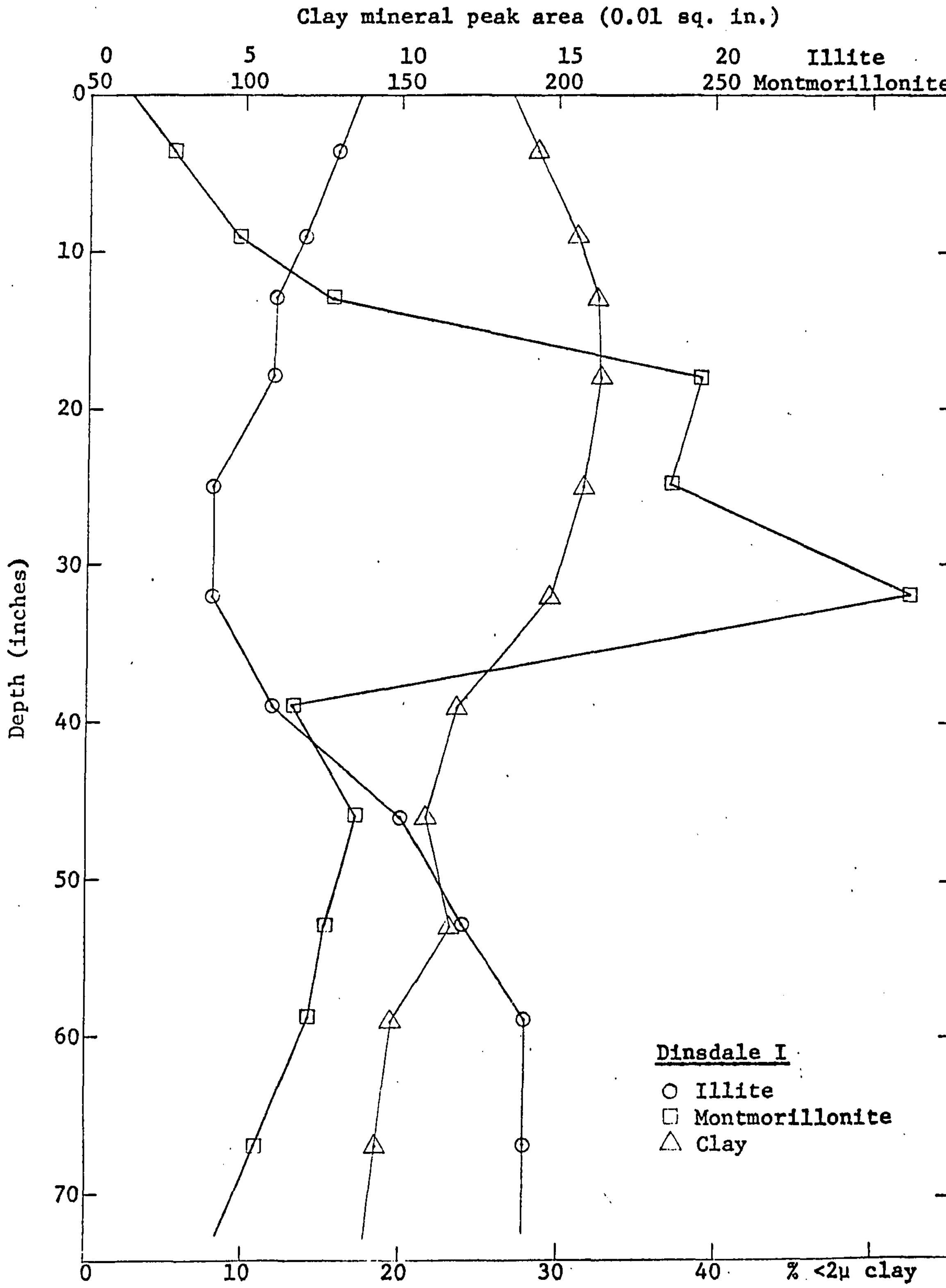

Clay mineral peak area (0.01 sq. in.)
0 5 10 15 20 Illite
50 100 150 200 250 Montmorillonite
Depth (inches)
0 10 20 30 40 50 60 70
0 10 20 30 40 % <2μ clay
Sac I
Illite
Montmorillonite
Clay

Figure 21. Profile distribution of montmorillonite and illite peak areas (0.01 sq.in.) and $<2\mu$ clay in Dinsdale, a well drained prairie soil from eastern Iowa



Clay mineral peak area (0.01 sq. in.)
0 5 10 15 20 Illite
50 100 150 200 250 Montmorillonite
0
10
20
30
40
50
60
70
Depth (inches)
0 10 20 30 40 % <2μ clay
Dinsdale I
Illite
Montmorillonite
Clay

from 77 to 311 (0.01 sq.in.) in the loess portion, decreases to approximately 110 (0.01 sq.in.), increases to 136 (0.01 sq.in.) and then decreases gradually to 103 (0.01 sq.in.) in the lower till horizon. The Sac soil has a similar montmorillonite distribution with depth; however, the maximum montmorillonite is shallower in this profile than in the Dinsdale profile. The montmorillonite is more uniform with depth in the poorly drained prairie soils, P738 (northwestern Iowa) and Maxfield (eastern Iowa) Table 9. For example the montmorillonite peak area ranges from 325 (0.01 sq.in.) in the surface to 404 (0.01 sq.in.) in the last loess or B2g horizon of the Maxfield. The montmorillonite intensity in the till portion of the poorly drained soils is similar to that of the well drained soils. The forested P739 profile has a much lower 36 (0.01 sq.in.) montmorillonite peak area in the surface layer, but has the same general profile distribution as the prairie soils.

The illite intensity of the thin loess/till soils generally decreases with depth in the loess portion and increases with depth in the till horizons. For instance in the well drained Dinsdale I profile the illite peak area decreases with depth from 8 to 4 (0.01 sq.in.) in the loess horizons and increases from 6 to 14 (0.01 sq.in.) in the till horizons. The poorly drained soils have a lower illite intensity in the surface than the well drained soils, but the lower horizons are similar in illite content.

The kaolinite content of the thin loess/till soils is generally low in all soils, but especially low in the northwestern Iowa soils. The kaolinite peak area generally increases slightly with depth and does not appear to be affected by drainage. The kaolinite peak area is slightly higher in the upper horizons of the forested P739 profile than in the prairie Dinsdale soils, but the lower horizons have a similar content.

The montmorillonite peak area for the thick loess soil, Tama, is similar to that of the loess portion of the thin loess/till soils; however, the Tama profile does not have the abrupt decrease at approximately 30 inches below the surface. The illite and kaolinite intensity of the Tama soil is lower than that of the thin loess/till soils. The upper portion of the surficial sediment/till soil, Kenyon, has a lower montmorillonite and illite content than the upper portion of the thin loess/till soil, but the till horizons have a similar content. Several lower till, C horizons (P734-15 and Till I-1, 2, 3 and 4), were analyzed and data indicates that the mineralogical composition is similar to the till horizons of the thin loess/till soils.

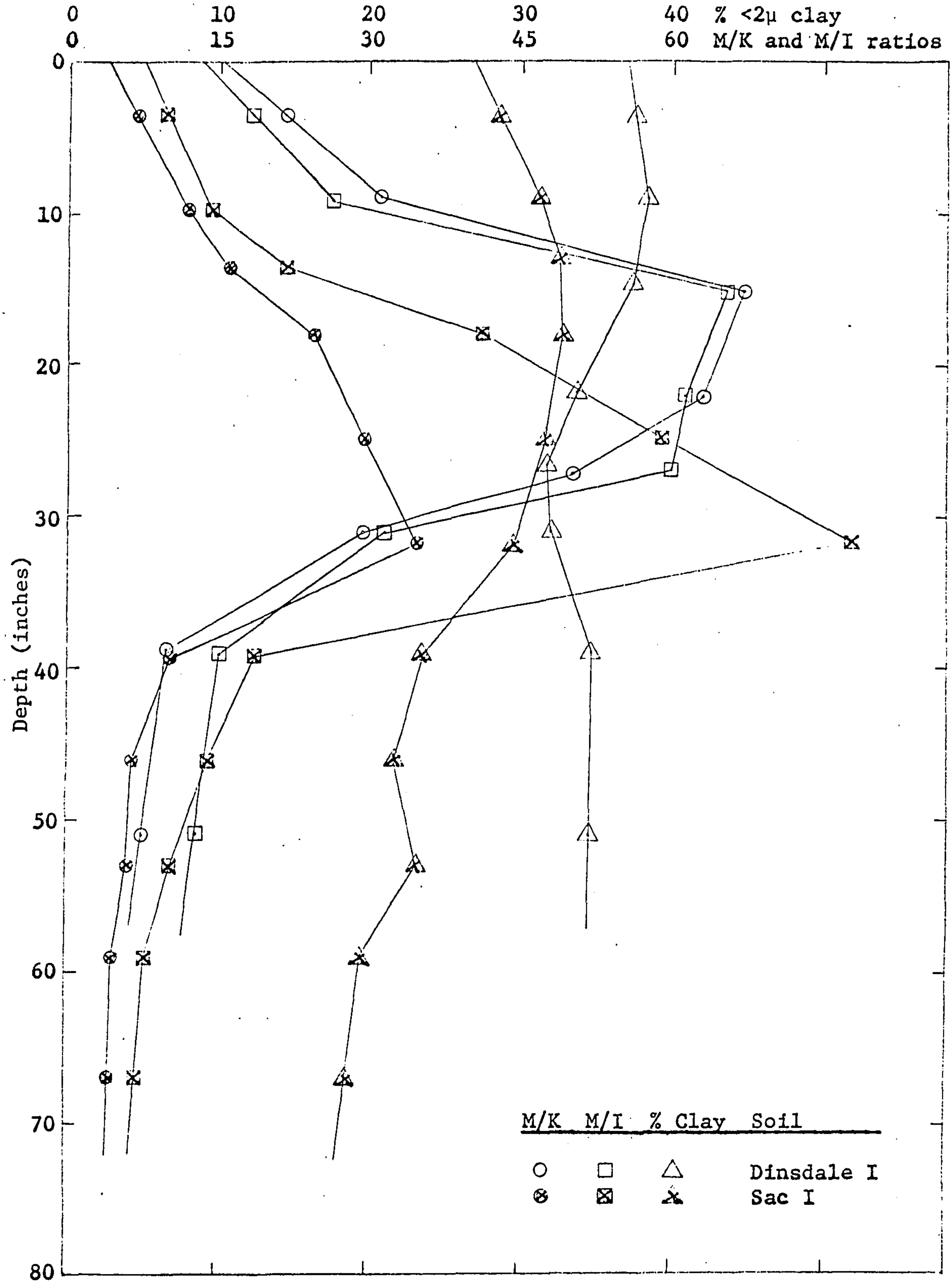
The Illinois and Ohio soils have a low, 43 (0.01 sq.in.), montmorillonite intensity in the surface and it does not increase as much with depth as the thin loess/till soils of Iowa. The Illinois and Ohio profile have a lower illite and higher kaolinite content in the upper horizons than the upper portion of the thin loess/till soils of Iowa. However, the till portion of the Illinois and Ohio soils has a much higher illite and lower kaolinite content than the till horizons of the Iowa soils.

In general the montmorillonite and kaolinite content of these soils is in the order: northwestern Iowa $<$ eastern Iowa $<$ eastern Illinois $<$ southwestern Ohio, whereas the illite content is in the order:

northwestern Iowa > eastern Iowa > eastern Illinois > southwestern Ohio. There are differences, however, due to other factors such as clay mineral composition of the parent material and variations in drainage and vegetation. The montmorillonite/kaolinite (M/K) and montmorillonite/illite (M/I) ratios may be better for comparison than the actual peak areas because they reduce the error from varying amounts of clay on the slide. The profile distribution of the M/K and M/I ratios for Dinsdale and Sac are given in Figure 22.

In all of the soils studied by means of x-ray diffraction except the Klinger profile, the illite peak area is directly related to the percent K content, or as the K content increases, the illite content also increases. The regression line and correlation coefficient were calculated for the Dinsdale and Sac profiles and are shown in Figures 23 and 24. The correlation coefficient is +0.91 for Dinsdale and +0.98 for Sac. Figure 25 is a summary of illite peak area and percent K relationships for all of the soils x-rayed.

Figure 22. Profile distribution of the montmorillonite/kaolinite, M/K, and montmorillonite/illite, M/I, ratios of peak areas for Dinsdale I and Sac I



0 10 20 30 40 % <2μ clay
0 15 30 45 60 M/K and M/I ratios
Depth (inches)
0 10 20 30 40 50 60 70 80
M/K M/I % Clay Soil
Dinsdale I
Sac I

Figure 23. Potassium in the $<1\mu$ clay and illite peak area (0.01 sq.in.) relationships in Dinsdale I from eastern Iowa

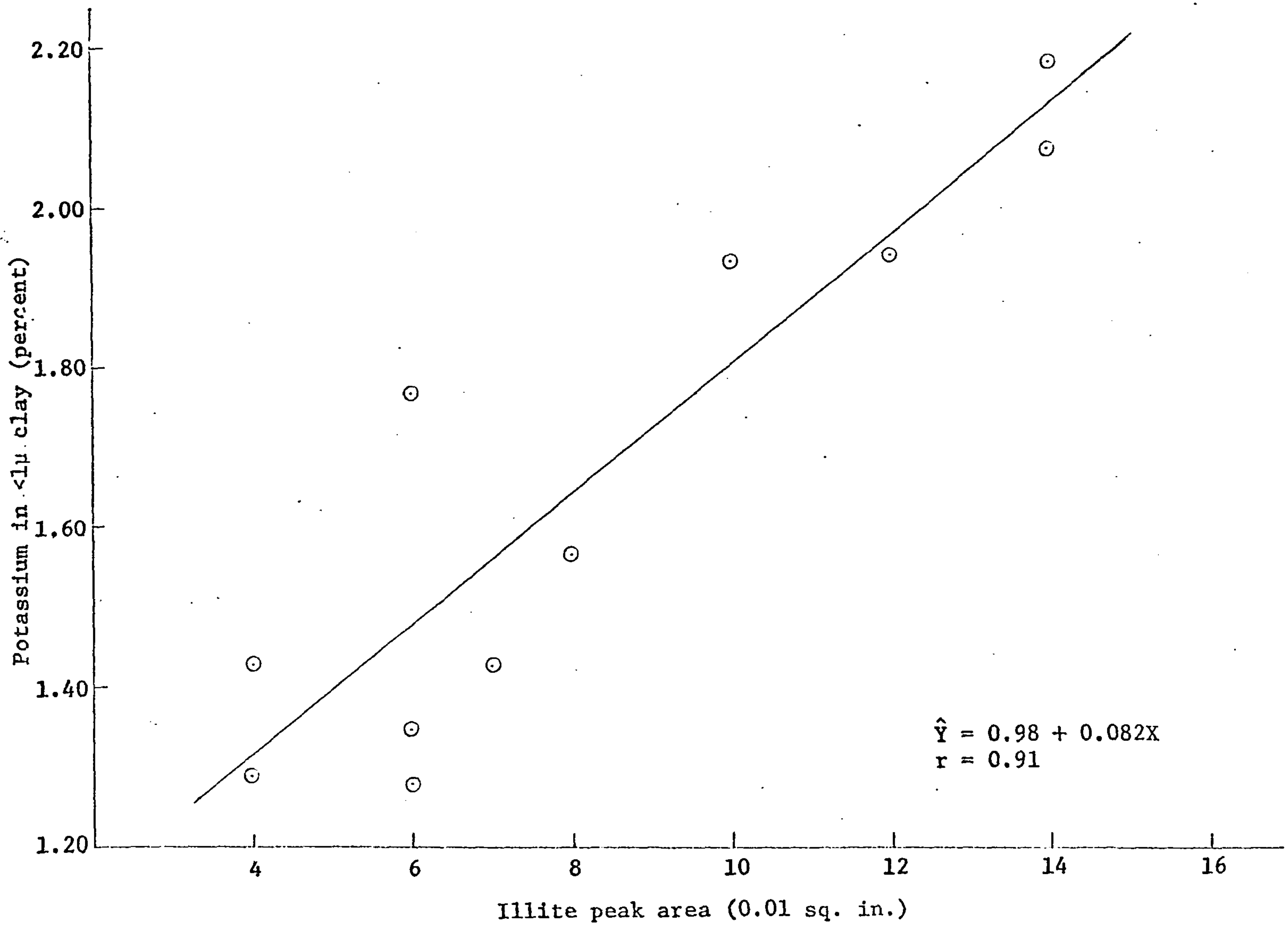
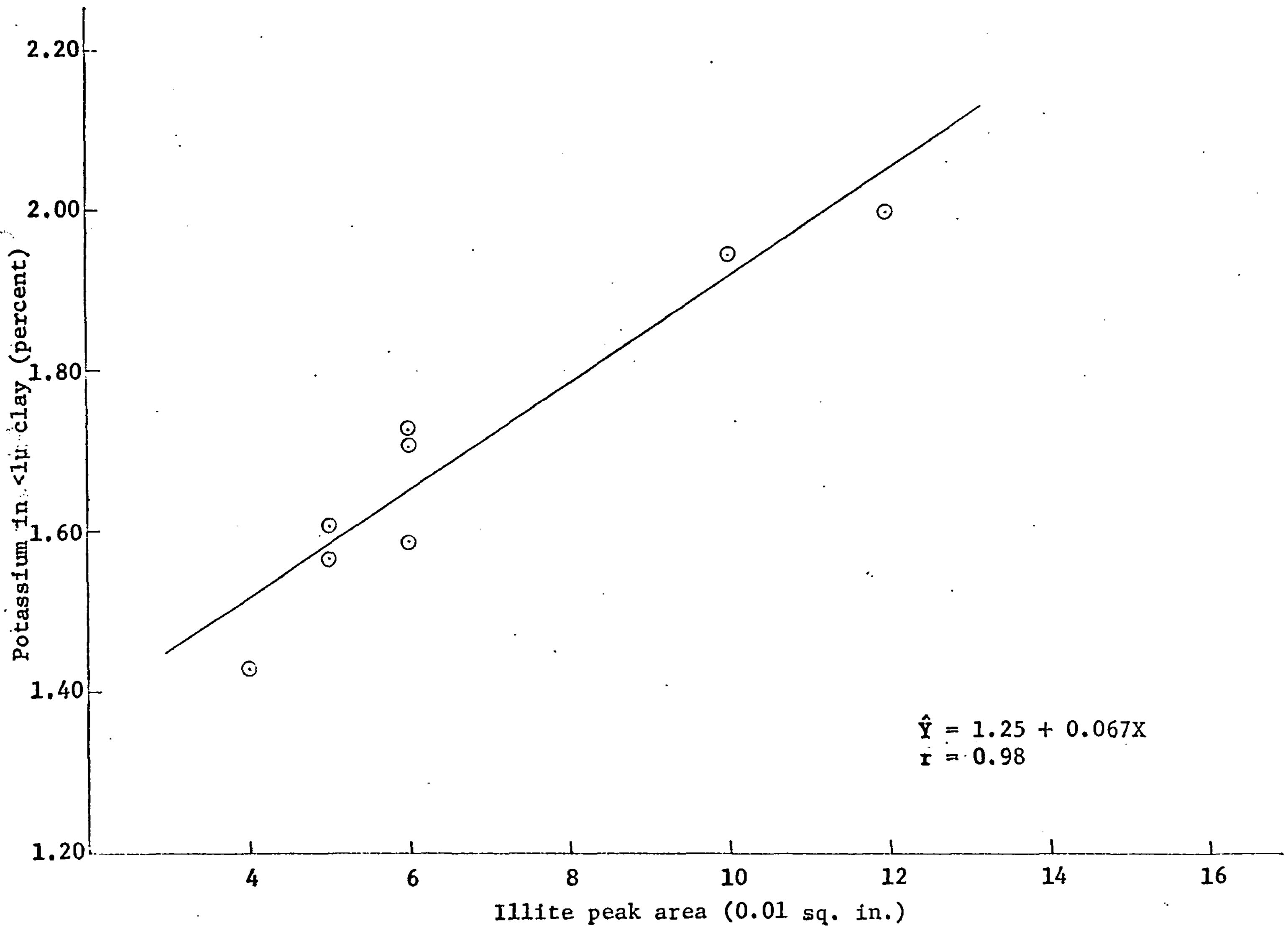
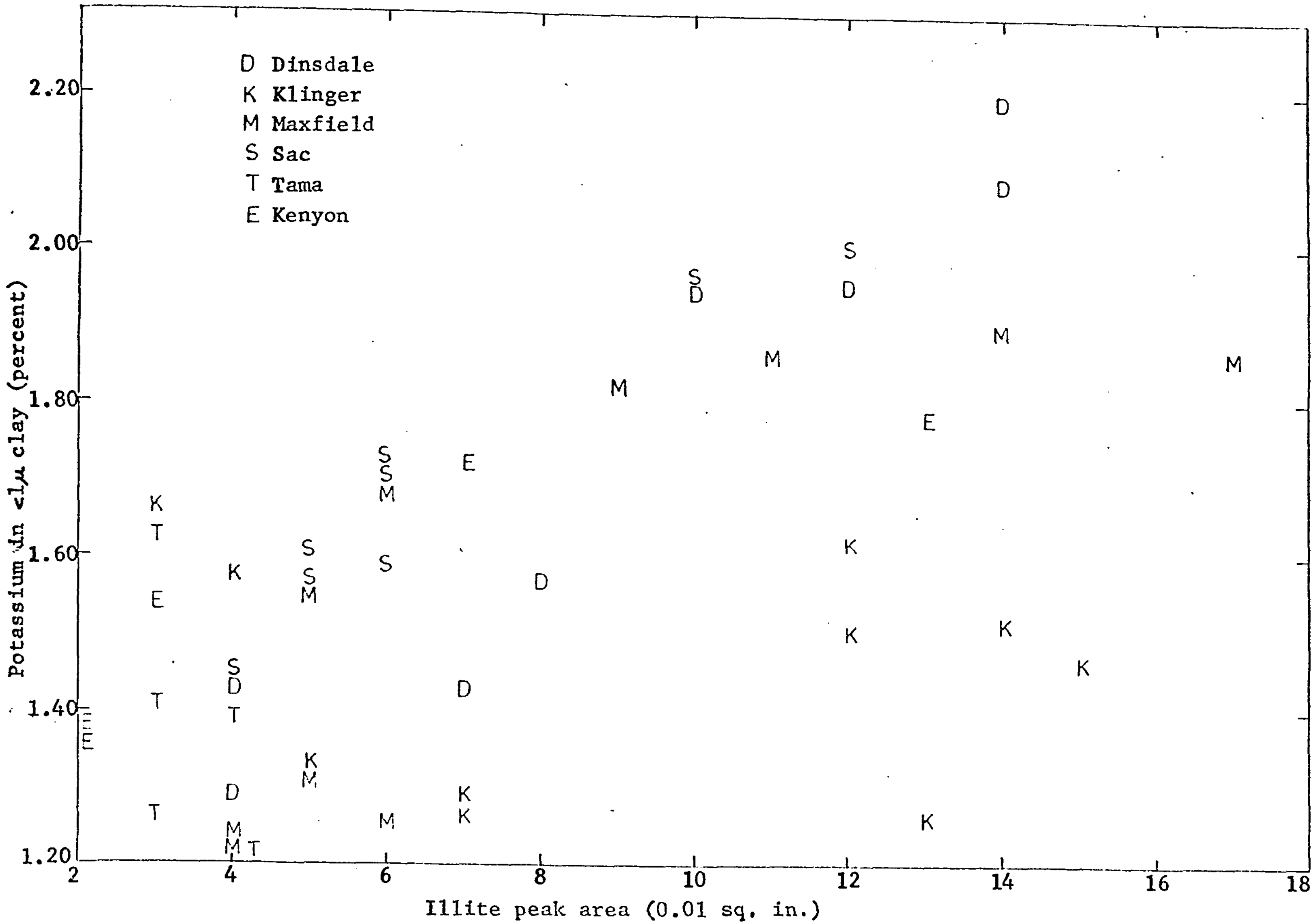

2.20
2.00
1.80
1.60
1.40
1.20
Potassium in <1μ clay (percent)
4
6
8
10
12
14
16
Illite peak area (0.01 sq. in.)
Ŷ = 0.98 + 0.082X
r = 0.91

Figure 24. Potassium in the <1μ clay and illite peak area (0.01 sq.in.) relationships in Sac I from northwestern Iowa



2.20
2.00
1.80
1.60
1.40
1.20
4
6
8
10
12
14
16
Potassium in <1μ clay (percent)
Illite peak area (0.01 sq. in.)
Ŷ = 1.25 + 0.067X
r = 0.98

Figure 25. Potassium in the <1μ clay and illite peak area (0.01 sq.in.) relationships for Dinsdale I, Klinger I, Maxfield I, Sac I, Tama and Kenyon profiles


D Dinsdale
K Klinger
M Maxfield
S Sac
T Tama
E Kenyon
Potassium in <1μ clay (percent)
Illite peak area (0.01 sq. in.)
2.20
2.00
1.80
1.60
1.40
1.20
2
4
6
8
10
12
14
16
18

DISCUSSION

The primary objectives of this study are to investigate the properties of the thin loess/till soils of northwestern and eastern Iowa. These soils are compared to thin loess/till soils from Illinois and Ohio and to associated soils from different parent material in eastern Iowa. Very little laboratory research had previously been conducted on the thin loess/till soils, and a firmer basis is needed at the series level to separate these soils. The additional knowledge obtained in this investigation further differentiates between the soils of northwestern and eastern Iowa as well as between the Iowa soils and those from Illinois and Ohio.

The nonexchangeable potassium and magnesium status and the relationship of these ions to other soil characteristics such as clay content, soil development, parent material, drainage and vegetation are emphasized. Some possible explanations are proposed for the profile distribution and variation of the nonexchangeable potassium and magnesium and the related leaching and recycling processes. A comparison is made of the nonexchangeable potassium and magnesium status of soils affected by different climatic, vegetative, drainage and parent material conditions. The effects of these environmental conditions are evaluated to determine if the various nonexchangeable potassium and magnesium differences can be attributed to any of the factors. The particle size distribution is discussed in order to characterize the soil textural development and to provide another criterion for the classification of the soil series. In addition the sodium tetraphenylboron extractable potassium and x-ray diffraction analysis results are discussed to further explain the nonexchangeable potassium and magnesium status of these soils.

Clay and Soil Formation

The thin loess/till soils have a two story profile of 20 to 40 inches of loess over till. Though there is a lithologic discontinuity reflected in particle size, in bulk density and porosity, generally there is not much evidence of discontinuity in the resultant profile properties due to soil processes. The lithologic discontinuities, moreover, have not been obliterated by pedogenesis. For example, the loess portion of the profile has a low sand content and high silt content, whereas the till portion has a high sand and low silt content.

The Sac soils and their prairie associates from northwestern Iowa have a higher clay content, a clay maximum horizon nearer the surface and less clay accumulation in the B horizon than their eastern Iowa analogues (Dinsdale and prairie associates). This is in agreement with the work of Foth and Riecken (1954). This is attributed to a less weathered condition and a slower rate of weathering in the northwestern Iowa area primarily because of the lower annual precipitation. The average annual precipitation in the Sac area is 26 to 28 inches; whereas in the Dinsdale area it is approximately 32 to 34 inches (see Figure 1). The temperature difference between the two areas probably is negligible. The amount of rainfall in a general sense controls the formation and development of a soil by regulating the rate and intensity of the physical and chemical processes that act on a parent material. It also regulates the leaching processes that remove the weathering products. It is assumed that the parent materials in the Sac and Dinsdale soil areas were very similar when deposited because of similar morphology and similar properties in the lower, apparently unaltered horizons. Length of time that the soils have been developing is probably quite similar for the two areas (Ruhe, et al. 1965, Ruhe and Scholtes, 1956). By comparing soils with similar vegetation and drainage (topography) the major variable of the five main soil forming factors is climate. As the soils have been developing for the same length of time in both areas, it is apparent that the climate must have a greater effect on the eastern Iowa soils to cause a greater degree of development as measured by B/A clay ratios and depth to maximum clay. This is attributed to the higher annual rainfall in eastern Iowa.

The drainage condition, both external and internal of a soil also has a minor effect on the rate of development of the soils studied. The poorly drained prairie soil has a higher clay content near the surface and has a lower B/A horizon clay ratio than the well drained sequence associate. Comparison of members of a drainage sequence from eastern Iowa (Dinsdale-Klinger-Maxfield) illustrates this (Figure 5). Similar relationships are evident in the northwestern Iowa (Sac-P737-P738) drainage sequence (Figure 3). However, the effect is more pronounced in eastern Iowa, apparently because of the higher annual rainfall. The effect of drainage on K and Mg will be discussed later.

Comparison of a vegetation sequence (Dinsdale-Waubeek-P739) in eastern Iowa shows that the forested soil has the lowest clay content in the surface, but has the most development (highest B/A horizon clay ratio and secondary clay accumulation in the B horizon (Figure 6). However, as has been noted by others (White and Riecken, 1955; Shrader, 1950), the amount of clay in the forest influenced soil is about the same as in the prairie-derived soils in the same area. Forested soils tend to have a more acid condition in the surface soil which would accelerate weathering and breakdown of the soil materials. These soils also have large amounts of litter on the surface which reduces runoff and increases infiltration of rainfall. Increased leaching could accelerate downward movement of clay and also accelerate weathering. These are probably the primary factors responsible for the greater development of forested soils as compared to prairie soils in the same area. A comparison cannot be made between the areas because forested soils comparable to P739 are not recognized in the northwestern part of the state. However, a comparison of a prairie/forest transition soil, P736, with the prairie soil, Sac, in Figures 3 and 4 shows that the former has a higher B/A horizon clay ratio.

The Illinois and Ohio soils studied are all from forest or prairie/forest vegetation, and the effect of prairie versus forest vegetation cannot be evaluated. Previous data on the Russell, Toronto and Xenia soils (Bailey et al., 1964) do not include information on the prairie sequence associates. However, based on other information for prairie and forested soils from eastern Illinois, the forest influenced soils have higher B/A horizon clay ratios than the prairie analogues. For example, imperfectly drained, forest influenced Blount has a B/A horizon clay ratio of 2.6, but the prairie analogue has a B/A horizon clay ratio of 1.4 (Wascher et al., 1960). Generally the Illinois and Ohio thin loess/till soils are more developed than the Iowa thin loess/till soils as evidenced by higher B/A horizon clay ratios, greater accumulation of clay in the B horizon and a greater depth to the clay maximum horizon. Primarily these characteristics are a result of higher annual precipitation in Illinois and Ohio.

In most cases the distribution of clay within a soil profile is an indication of the degree of weathering and development that the soil has undergone. Soil development as discussed here represents primarily the accumulation of clay in the B horizon due to movement from the A horizon or genetic formation in place by physical and chemical alteration of materials present. There may also be an accumulation of other soil constituents in the B horizon. This is assumed to reflect the effects of the soil forming processes with time. Climate, and more specifically the annual precipitation, probably has the greatest effect on the degree of soil development in the group of soils of this study. In making this statement about the importance of climate it is to be noted that the soils studied have a limited range of development, and furthermore have quite homogeneous parent material and time factors of soil formation.

Potassium and Soil Formation in the Thin Loess/till Soils

It has long been known that in general the loess-derived soils of western Iowa are higher in total potassium than eastern Iowa soils

(Brown, 1914). Recent studies (Protz, 1965; Wells, 1963) on individual soil series have also shown that the clay fraction of western Iowa loess soils are in general higher in K. These studies related the differences in K status to climate, principally rainfall.

In the present study the K status was investigated to determine if criteria, other than general morphology and clay distribution, could be developed to aid in classifying and characterizing the thin loess/till soils of northwestern and eastern Iowa.

Nonexchangeable potassium

The northwestern Iowa thin loess/till soils have a higher K content and less difference between the well and poorly drained sequence members than comparable soils in eastern Iowa (Table 10). If originally the parent materials were similar in composition and are of the same age, these differences are attributable to more intense weathering and leaching, due primarily to higher annual precipitation in eastern Iowa. Originally the loess portion of these soils probably was slightly lower in K than the till portion, but now the surface layers are slightly higher, and the subsoil is slightly lower than the general average in the till. The upper 12 to 15 inches of the till is slightly weathered (slight decrease in K content), but the lower portion is quite uniform with depth to 15 feet and is very similar to the apparently unaltered (unoxidized and unleached) till samples from 50 to 100 feet below the surface.

In eastern Iowa the K distribution with depth in the loess portion of the thin loess/till well drained prairie soils is similar to that of the Tama profile; however, the till portion is slightly lower than the

Table 10. Comparison of nonexchangeable potassium and related data for the groups of soils studied

		Natural drainage class											
		Well				Somewhat poor				Poor			
Parent material	Vege-ta-tion	K[a] %	K x clay[b]	B horizon K rel.[c] ppm	%	K[a] %	K x clay[b]	B horizon K rel.[a] ppm	%	K[a] %	K x clay[b]	B horizon K rel.[a] ppm	%
						Northwestern Iowa Soils							
Thin loess/till	P	1.57	59	4900	93	1.45	49	3970	86	1.51	58	3750	72
(20-40 inches)	P/F					1.56	42						
						Eastern Iowa Soils							
Thin loess/till	P	1.47	46	3750	89	1.49	43	3040	77	1.19	40	3065	85
(20-40 inches)	P/F	1.65	39			1.35	39						
(Dinsdale sequence)	F	2.02	46	3575	80								
Thick loess	P	1.52	47			1.65	54			1.25	47		
(>40 inches)	P/F	2.00	47			2.02	43			1.94	39		
(Tama sequence)	F	1.85	45			1.78	33			1.47	32		
Surficial sediments	P	1.42	32	2460		1.26	30			1.20	35		
(Kenyon sequence)													
						Illinois Soils							
Thin loess/till	P/F					2.10	42						
(Russell sequence)	F	2.15	47	5030	74	1.41	45						

[a] Nonexchangeable potassium, K, in <1μ clay fraction (value is an average of the upper 3 horizons of the profile).

[b] Percent K in <1μ x percent <2μ clay.

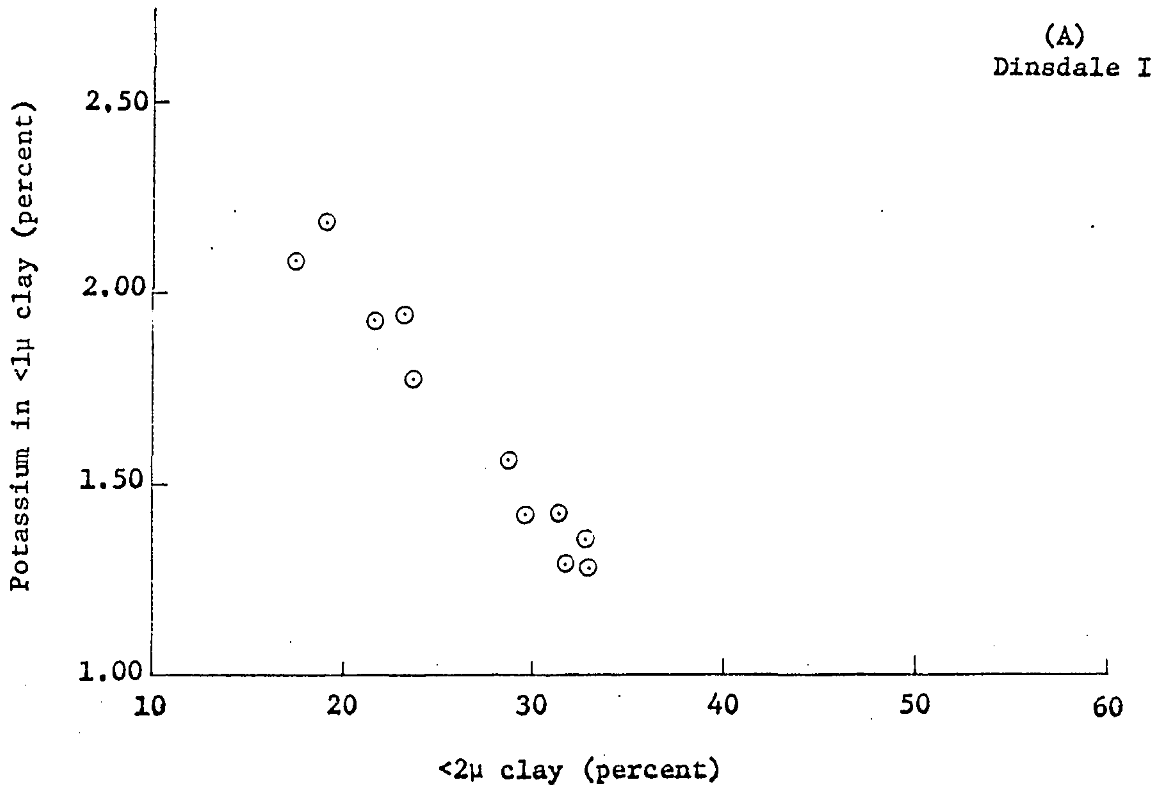
[c] Potassium released by B horizon to sodium tetraphenylboron in 7 day period (ppm and percent of total K released).

substratum (loess) of the Tama soil. The K distribution of the thin loess/till well drained prairie soils is higher than the upper portion of the Kenyon soils, but the substratum (till) of both groups of soils is about the same. The K distribution in the upper part of the Iowa thin loess/till forest soils is similar to analogous soils in Illinois and Ohio, but the till substratum of the Illinois and Ohio soils is much higher in K. This is apparently due to a higher content of potassium-rich minerals, principally illite, in the Illinois and Ohio tills.

The K content of the $<1\mu$ clay fraction of the soils studied is inversely related to the $<2\mu$ clay content, or as the clay content increases, the K content decreases as shown by Figures 3-10 and 26-28. As weathering proceeds, the K is depleted from the interlayer position of the illitic clay minerals, and through intermediate processes and stages the clay minerals are gradually converted to the montmorillonitic type. The K then becomes part of the leaching process, and the tendency is to move downward and out of the soil profile system; however, this is confounded by vegetative recycling, reversion back to the nonexchangeable form in the upper horizons, and also by natural drainage. Potassium is a major plant nutrient and more of this ion is recycled by plants than the Mg, Na or Ca ions. The K is brought to the surface by plants, and as it leaches into the soil, some of it reverts back to the non-exchangeable form. This causes an accumulation in the surface horizons and a depletion in the subsoil; in the soils studied the recycling rate apparently exceeds the leaching rate of the potassium.

The drainage condition also affects the K status of these soils.

Figure 26. Potassium in the <1μ clay and <2μ clay relationships in Dinsdale I (A) and Sac I (B); well drained prairie soils from eastern and northwestern Iowa


(A)
Dinsdale I
Potassium in <1μ clay (percent)
2.50
2.00
1.50
1.00
10
20
30
40
50
60
<2μ clay (percent)

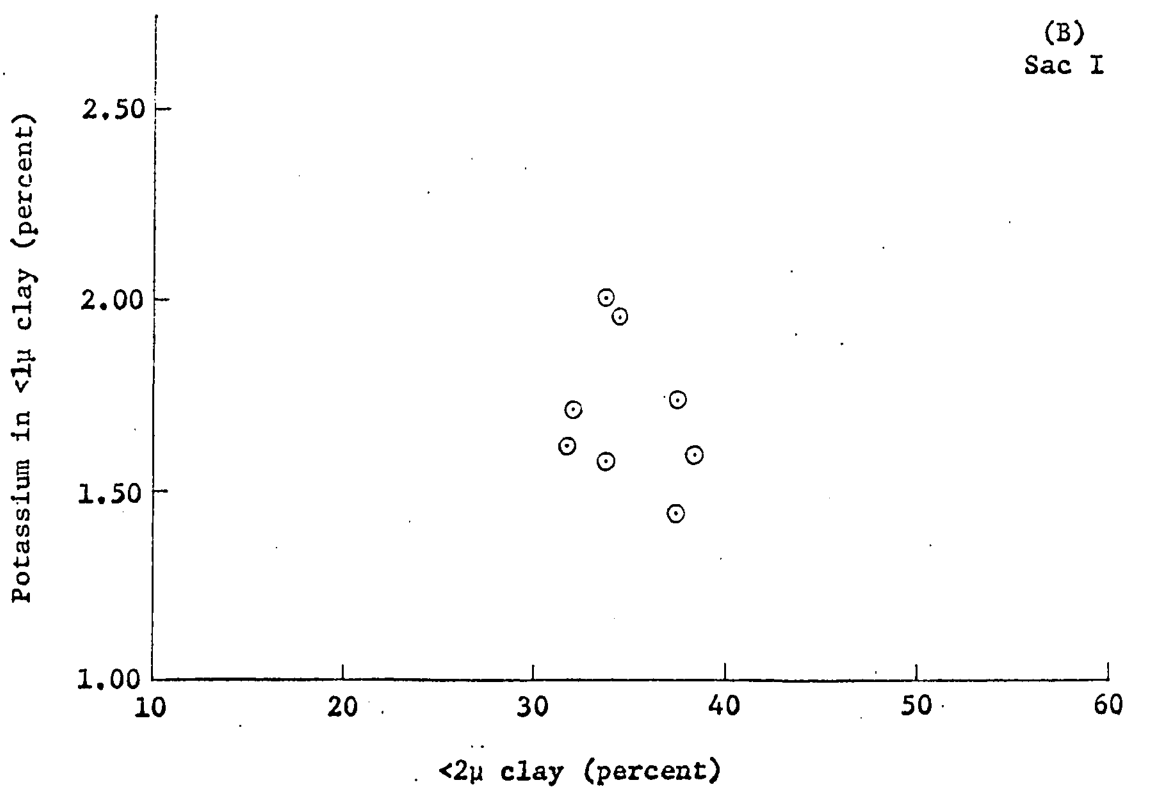
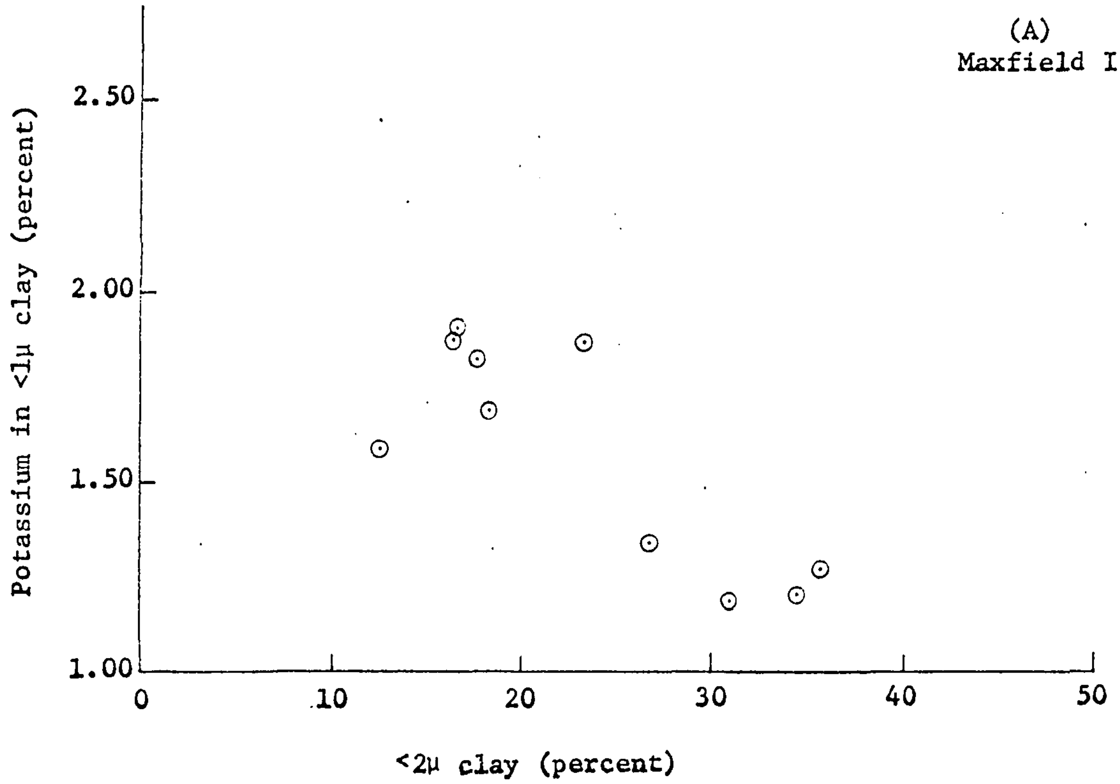

(B)
Sac I
Potassium in <1μ clay (percent)
2.50
2.00
1.50
1.00
10
20
30
40
50
60
<2μ clay (percent)

Figure 27. Potassium in the $<1\mu$ clay and $<2\mu$ clay relationships in Maxfield (A) and P738 (B); poorly drained prairie soils from eastern and northwestern Iowa


(A)
Maxfield I
Potassium in <1μ clay (percent)
2.50
2.00
1.50
1.00
0
10
20
30
40
50
<2μ clay (percent)

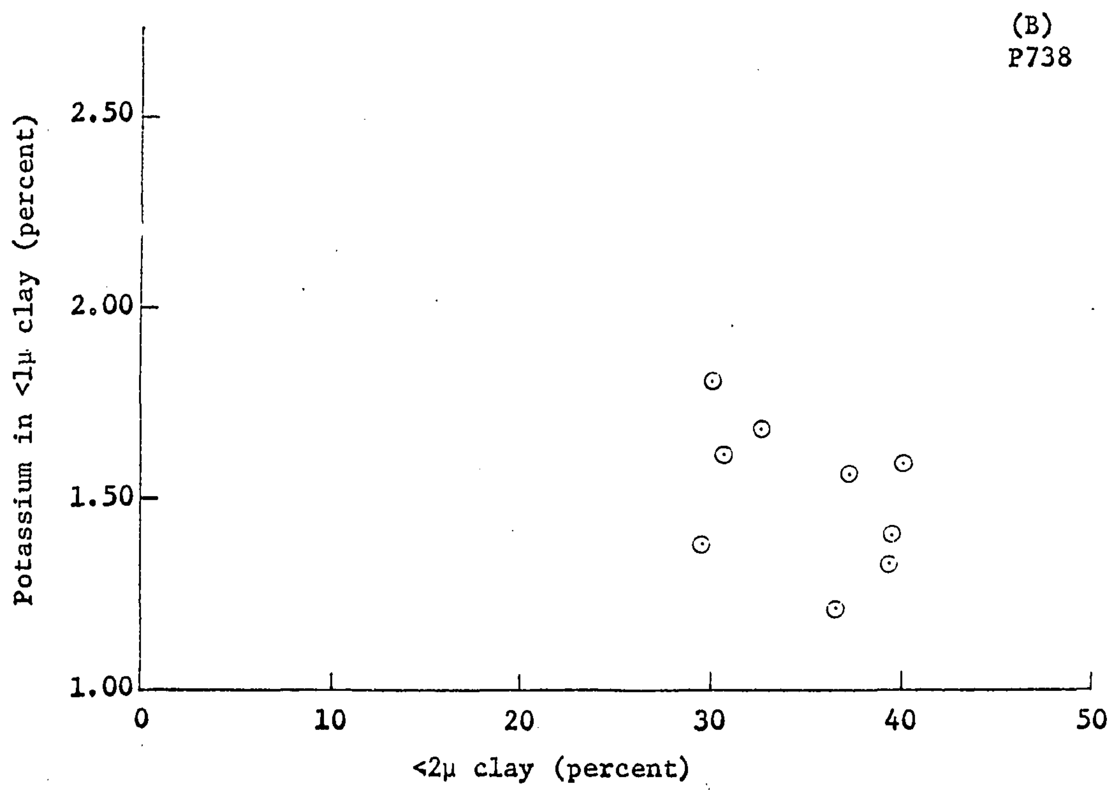
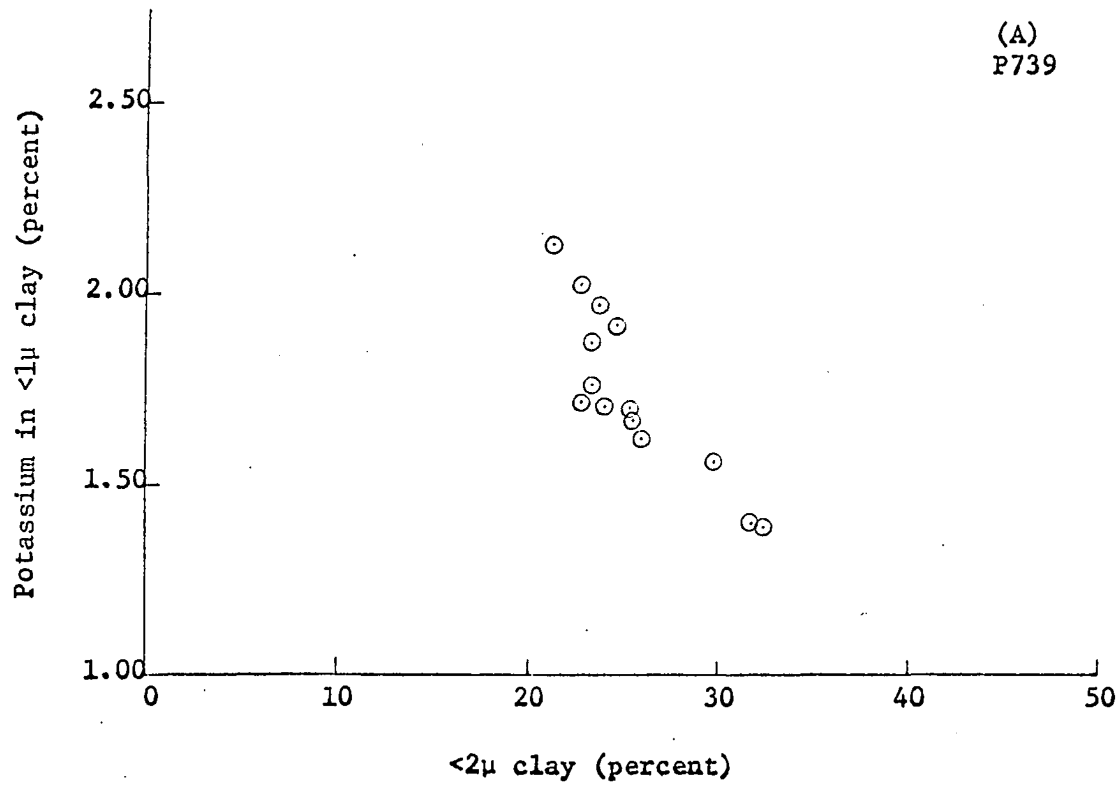
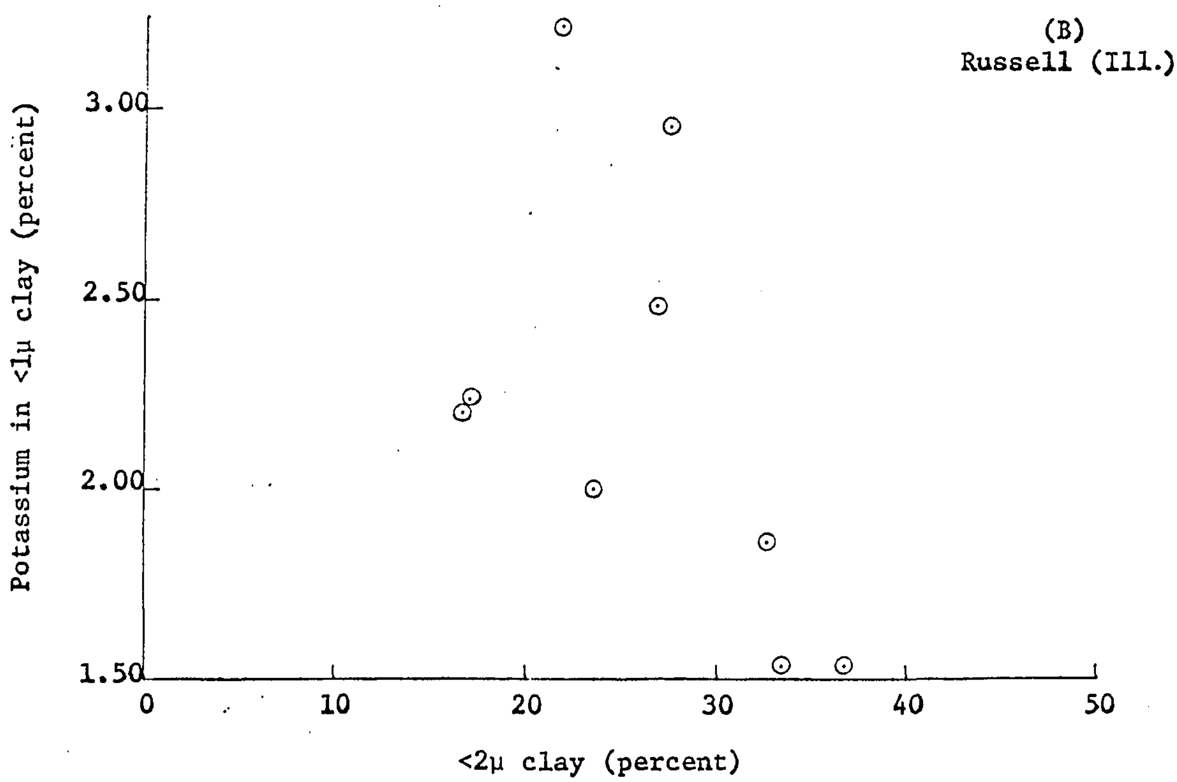

(B)
P738
Potassium in <1μ clay (percent)
2.50
2.00
1.50
1.00
0
10
20
30
40
50
<2μ clay (percent)

Figure 28. Potassium in the $<1\mu$ clay and $<2\mu$ clay relationships in P739 (A) and Russell, Illinois, (B); well drained, forested soils


(A)
P739
Potassium in <1μ clay (percent)
2.50
2.00
1.50
1.00
0
10
20
30
40
50
<2μ clay (percent)


(B)
Russell (Ill.)
Potassium in <1μ clay (percent)
3.00
2.50
2.00
1.50
0
10
20
30
40
50
<2μ clay (percent)

The well drained soils have a higher K content in the upper part of the profile in both the northwestern and eastern Iowa areas, but in eastern Iowa the difference is more pronounced.

The forested soil, P739, has a higher K content in the upper part of the profile than the prairie soil, Dinsdale. The forested soil is more acid, so weathering is enhanced, and the leaching rate is probably higher because of favorable infiltration conditions. The forest vegetation apparently recycles more K than prairie vegetation as the K content of the clay of the upper layers in forest influenced soils is higher than in prairie sequence members (Table 10).

<u>Sodium tetraphenylboron extractable potassium</u>

The Dinsdale soils of eastern Iowa released a greater amount of K with sodium tetraphenylboron extraction in the B horizon than in the upper horizon, but the B horizon also has a higher clay content (see Tables 10 and 11). Therefore, the amount of K released/clay ratio is about the same for both horizons (Table 11), indicating the weathering is similar in both horizons. The upper horizon, however, has a higher K content, so the percentage of total K released is slightly greater in the B horizon indicating a less weathered condition in that horizon. The till substratum has a higher release, but the percentage released is approximately the same. The Sac soil of northwestern Iowa released a greater amount of K than the Dinsdale soil, but the B horizon also released more than the upper horizon. However, the upper horizon of the Sac soil has the highest clay content, so the amount of K released/clay

Table 11. Comparison of sodium tetraphenylboron extractable potassium and related data for the Dinsdale and Sac profiles

Sample number	Depth (inches)	Horizon	$<2\mu$ clay %	7 day K release ppm	Grams K released/ 100g clay	Non-exch. K %	%K released	60 day K release ppm
				Dinsdale P704				
P704-2	7-11	A12	31.2	3470	1.11	1.43	78	4520
4	15-21	B1	32.9	3750	1.14	1.28	89	5000
				Sac P746				
P746-2	7-11	A3	38.4	4180	1.09	1.59	69	5600
4	18-25	B21	33.6	4900	1.46	1.57	93	5950

ratio was much greater for the B horizon. The K content is approximately the same for both horizons, so the percentage of total K released is higher in the B horizon indicating a less weathered condition in that horizon. The upper part of the till portion of the Sac soils release approximately the same amount of K as the till substratum of the eastern Iowa soils, but the lower part of the Sac profile is confounded by the high calcium carbonate content. In general the data indicate that the eastern Iowa soils weather faster and are weathered to a greater degree than the northwestern Iowa soils. This is probably due to the higher annual precipitation in the eastern part of the state.

The poorly drained soils of each area released less K than the associated well drained soils, and the poorly drained P738 of northwestern

Iowa released more K than the poorly drained Maxfield of eastern Iowa. The amount of K released/clay ratio and the percentage K released (see Table 7) indicate that the poorly drained soils are generally less weathered than the corresponding well drained soils. The till substratum of the poorly drained soils also releases less K than the substratum of the well drained soils.

The forested soil, P739, released less K than the prairie soil, Dinsdale, but the amount of K released/clay ratio is approximately the same. However, the percentage of K released is lower than that of the prairie soil. Apparently the more weathered and leached condition due to forest vegetation causes the lower release of K by the forested soil.

The Russell soil from Illinois released less K in the surface, but much more in the subsoil than the eastern Iowa soils. The amount of K released/clay ratio is much higher, but the percentage of total K released is lower than the eastern Iowa soils. This indicates that the Illinois soils are more weathered in the surface, probably due to higher annual precipitation and forest vegetation, but the greater K release in the lower horizons is due to a higher K content in the parent material.

The amount of K released with NaTPB is directly related to the percent K times percent $<2\mu$ clay as shown in Figure 37 for a 7 day period and Figure 38 for a 60 day period. This plot includes values for all of the soils analyzed for K release (see Tables 7 and 8). These soils are forming in a variety of parent materials, and included are a number of horizons of different textural development. The correlation coefficients for these relationships are 0.75 for the 7 day period and 0.64 for the 60 day period. The K release determinations were made on whole soil, but apparently the clay fraction is the source of most of the clay released. According to Pratt (1952), the clay size fraction of a soil contributes approximately 60 percent of the K released. The samples with a high K content also released high amounts of K with NaTPB, but the high clay content samples generally have a low K content. Therefore, the K times clay is a better basis for explanation of the K released than the K content or clay content alone because most of the K released comes from the clay fraction, but the clay is not completely depleted of K. The soils with a high K content generally release a high percentage of K in a short time and then continue to release more K with longer periods of time. The soils with a low K content release the bulk of the K in a short period and may not release much more in a longer period.

Potassium and soil classification

Marbut (1922) listed chemical composition of soil as a criterion to be used in soil classification. The Nonexchangeable potassium status of the soils investigated is in agreement with recent studies by Wells (1963) and Protz (1965). The K content of the $<1\mu$ clay of the thin loess/till soils is higher in northwestern Iowa than in eastern Iowa and the soils from the northwestern area release more K with NaTPB than those from the eastern area. These differences are attributable to the higher annual precipitation in the eastern part of the state. The soils from the two areas also differ in the profile distribution of K. The eastern Iowa soils have more textural development than the northwestern Iowa soils as evidenced by higher B/A horizon clay ratios and depths to the maximum clay, but within the profile the clay maximum horizon has the minimum K content. The eastern Iowa soils have a lower content of, and a greater difference between the minimum and maximum amount of K in the profile than the northwestern Iowa soils. These characteristic differences in the potassium relationships are recommended as a criterion for separation at the series level of the soils of the Sac sequence of northwestern Iowa from those of the Dinsdale sequence of eastern Iowa. This criterion substantiates the morphological and clay distribution criteria presently used for classification of these soils.

Magnesium and Soil Formation in the Thin Loess/till Soils

Catherwood and DeTurk (1928) and Bray and DeTurk (1930) show that in Illinois soils the exchangeable magnesium increases with increasing textural development. Hutton (1951) and Ulrich (1951) reported similar relationships for soils from Iowa. Bray (1936, 1937) showed that nonexchangeable magnesium content in the clay fraction of soils decreased with increasing development. Barshad (1960b) indicated that Mg in the clay decreased as base saturation decreased. Protz (1965) showed that nonexchangeable magnesium correlates with distance along a traverse from eastern Nebraska to western Illinois and that the Mg content of these soils is an expression of climate, primarily rainfall. Protz also noted that within the profiles the Mg content decreased with depth, but the base saturation increased with depth. In the present study the Mg status of the thin loess/till soils of Iowa was investigated to determine if additional criteria for classification of these soils could be found.

The Sac and related soils of northwestern Iowa have a higher non-exchangeable magnesium, Mg, content in the $<1\mu$ clay fraction of the upper part of the profile than the Dinsdale and related soils of eastern Iowa (summarized in Table 12). This is in agreement with the relationships reported by Protz (1965). The Mg content of the lower part of the profile is uniform and about the same in both areas. Since it is assumed that the parent materials originally had a similar Mg content and are about the same age, the higher Mg content in the northwestern area is attributed to a less weathered condition and a lesser weathering intensity. The profile distribution of Mg in the Dinsdale soils is very similar to the Tama soils, but is slightly higher than the upper part of the Kenyon profile. This indicates that the loamy surficial sediments at the upper part of the Kenyon profile were lower in Mg content originally because the climatic conditions are similar within the area. The Mg content of the loess portion of the thin loess/till soils of Iowa is very similar to that of comparable soils in Illinois and Ohio; however the till portion of the Illinois and Ohio profiles is higher than that of the Iowa soils. This is attributed to a higher Mg content in the parent material due to a higher content of magnesium-rich minerals or to a less weathered condition of the till at the time of deposition as reported by Willman (1963). There does not seem to be enough depletion in the upper part of the profile to account for the higher content by leaching alone.

Table 12. Comparison of nonexchangeable magnesium and related data for the groups of soils studied

Parent material	Vegetation	Well: Mg[a] %	Well: Depth to 1.2% Mg[b] in.	Well: B/A Clay ratio[b]	Well: Clay max. in.[b]	Somewhat poor: Mg %	Somewhat poor: Depth to 1.2% Mg in.	Somewhat poor: B/A clay ratio	Somewhat poor: Depth to clay max. in.	Poor: Mg %	Poor: Depth to 1.2% Mg in.	Poor: B/A clay ratio	Poor: Depth to clay max. in.
Northwestern Iowa Soils													
Thin loess/till (20-40 inches)	P	1.14	18	1.02	9	1.18	20	1.02	10	1.19	20	1.08	17
	P/F					0.95	>60	1.67	21				
Thick loess (Primghar sequence)[c]	P	1.28	7	1.05	9	1.14	16	1.00	9				
Eastern Iowa Soils													
Thin loess/till (20 to 40 inches)	P	0.96	>73	1.11	15	1.02	>68	1.05	16	0.98	24	1.08	16
	P/F	0.99	>100	1.58	21	0.93	>110	1.59	19				
	F	1.02	>90	1.41	23								
Thick loess (>40 inches) (Tama sequence)	P	1.08	25	1.16	23	1.04	36	1.14	20	1.11	22	1.10	15
	P/F	0.92	>50	1.54	20	1.14	40	1.68	32	0.95	50	2.16	20
	F	1.00	>50	1.50	24	0.98	50	2.26	20	1.07	40	2.15	21
Surficial sediments (Kenyon sequence)	P	0.92	>100	1.56[d]	27	0.89	50	1.24[d]	21	0.92	>95	1.10[d]	17

[a]Nonexchangeable magnesium in <1μ clay fraction (value is average of upper 4 horizons in profile.

[b]Value is average of profiles when more than one analyzed.

[c]Data from Protz (1965).

[d]The B/A horizons for soils of the Kenyon sequence are unreal because the B horizon is in till and is originally higher in clay.

Table 12. (Continued)

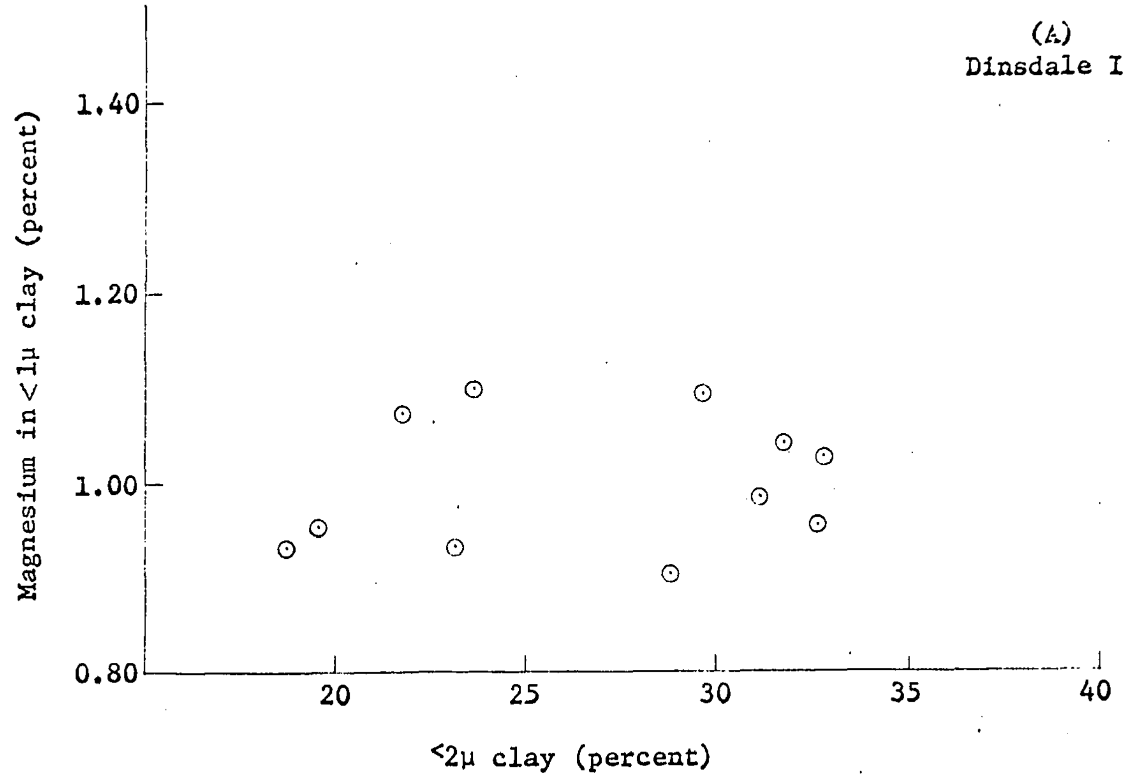
Parent material	Vegetation	Well: Mg % [a]	Well: Depth to 1.2% Mg in. [b]	Well: B/A Clay ratio [b]	Well: Clay max. in. [b]	Somewhat poor: Mg %	Somewhat poor: Depth to 1.2% Mg in.	Somewhat poor: B/A clay ratio	Somewhat poor: Depth to clay max. in.	Poor: Mg %	Poor: Depth to 1.2% Mg in.	Poor: B/A clay ratio	Poor: Depth to clay max. in.
Eastern Iowa Soils (continued)													
Thick loess (Otley sequence)[c]	P	1.07	26	1.31	17	0.99	35	1.26	23	0.97	28	1.22	18
Illinois and Ohio Soils													
Thin loess/till	P/F					1.07	32	1.65	26				
(Russell sequence)	F	0.99	22	2.05	25	0.88	38	2.03	20				

The profile distribution of Mg in the <1μ clay fraction does not appear to be directly related to the distribution of <2μ clay (Figures 11-17 and 29-30), although the soils with the higher clay content have a lower Mg content. The Mg ion is a component of the octahedral layer lattice which must be broken down before the Mg becomes exchangeable and leaches as postulated by Protz (1965) and Kerr et al. (1956). It is generally the fine fractions of clay that move and accumulate in the B horizon, so the Mg^{++} and clay probably move independently. As soil development proceeds, the clay accumulates in the B horizon. The Mg^{++} apparently is not affected by clay accumulation and continues to leach downward. Magnesium is not a major plant nutrient, and plants do not recycle large quantities of this ion. Magnesium is not readily reverted back to the nonexchangeable form like potassium, so there is no mechanism to retard the downward leaching. There is not an accumulation of Mg in the substratum apparently because the amount released by weathering is small.

The drainage condition also affects the Mg content of the soils, but not as much as the K content. The difference between the well and poorly drained soils also is not as pronounced as the K relationship, but it is more pronounced in eastern than northwestern Iowa. This is apparently due to the higher annual precipitation in the eastern part of the state.

Vegetation does not have any apparent effect on the Mg content of these soils because the profile distribution of Mg in a vegetation sequence (see Figure 13) is very similar. The upper two or three horizons

Figure 29. Magnesium in the $<1\mu$ clay and $<2\mu$ clay relationships in Dinsdale I (A) and Sac (B); well drained prairie soils from eastern and northwestern Iowa


(A)
Dinsdale I
Magnesium in < 1μ clay (percent)
1.40
1.20
1.00
0.80
20
25
30
35
40
<2μ clay (percent)

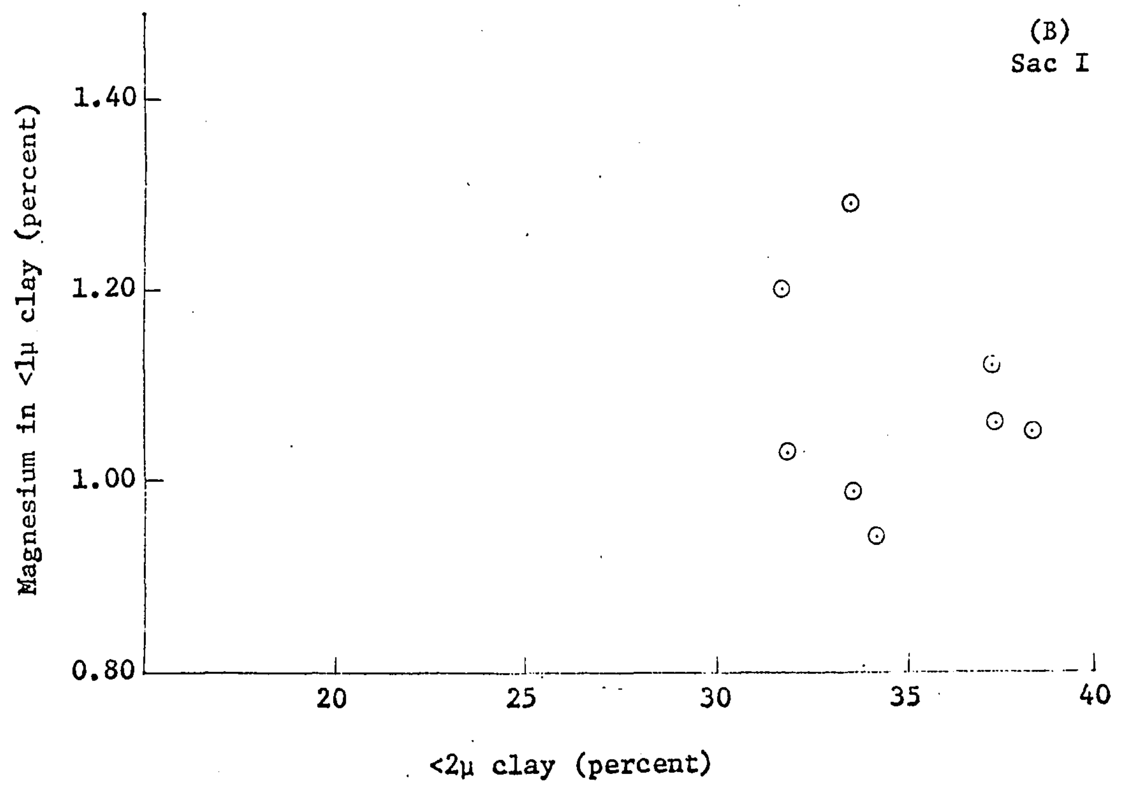
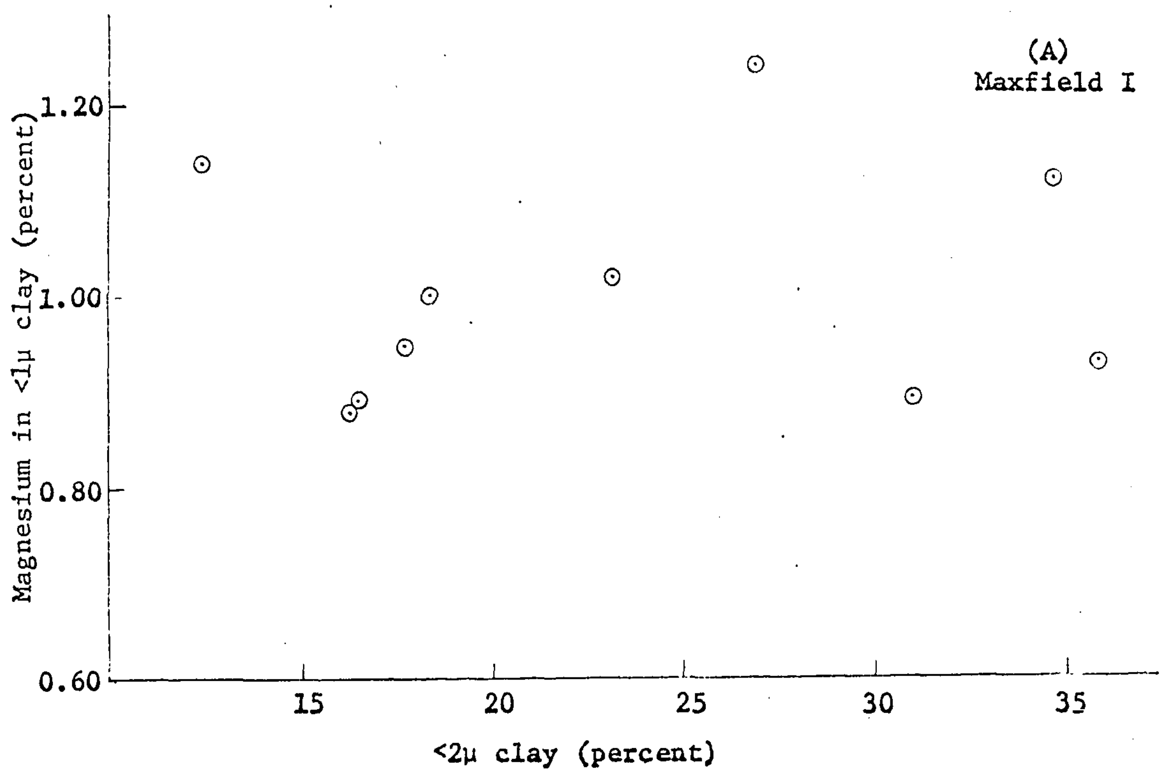
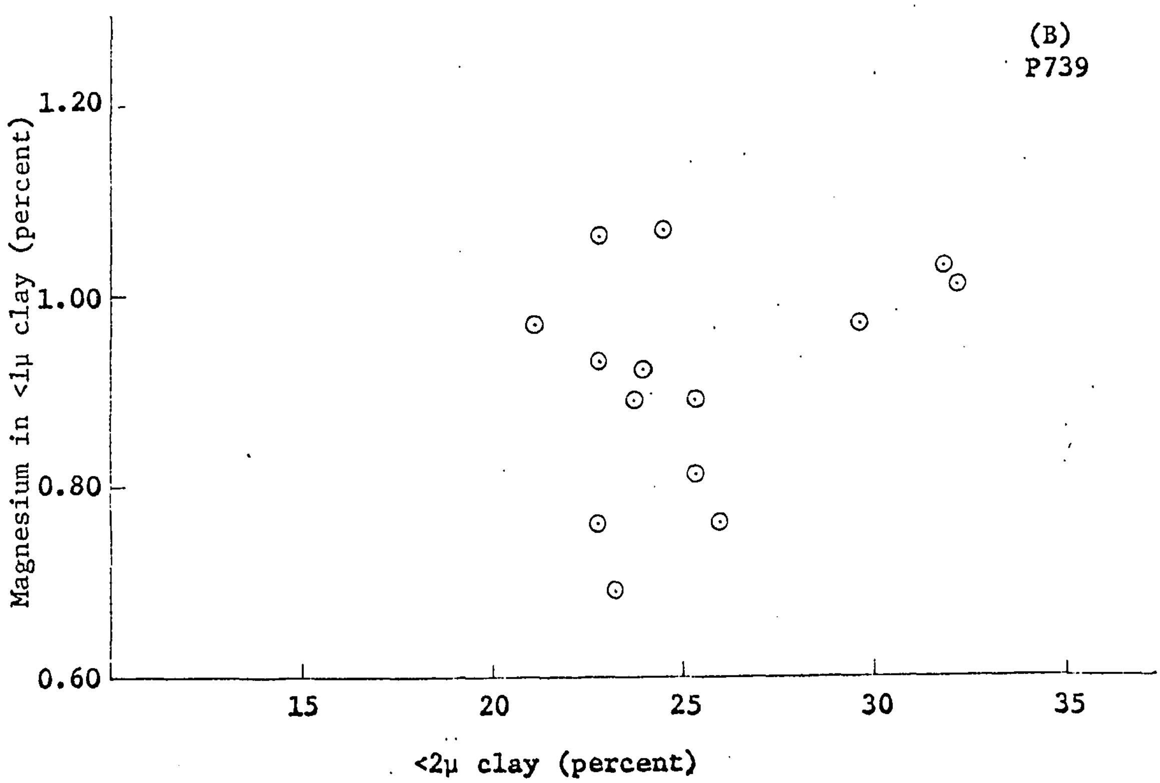

(B)
Sac I
Magnesium in <1μ clay (percent)
1.40
1.20
1.00
0.80
20
25
30
35
40
<2μ clay (percent)

Figure 30. Magnesium in the $<1\mu$ clay and $<2\mu$ clay relationships in Maxfield I (A) and P739 (B); poorly drained prairie and well drained, forested soils respectively from eastern Iowa


(A)
Maxfield I
Magnesium in <1μ clay (percent)
1.20
1.00
0.80
0.60
15
20
25
30
35
<2μ clay (percent)

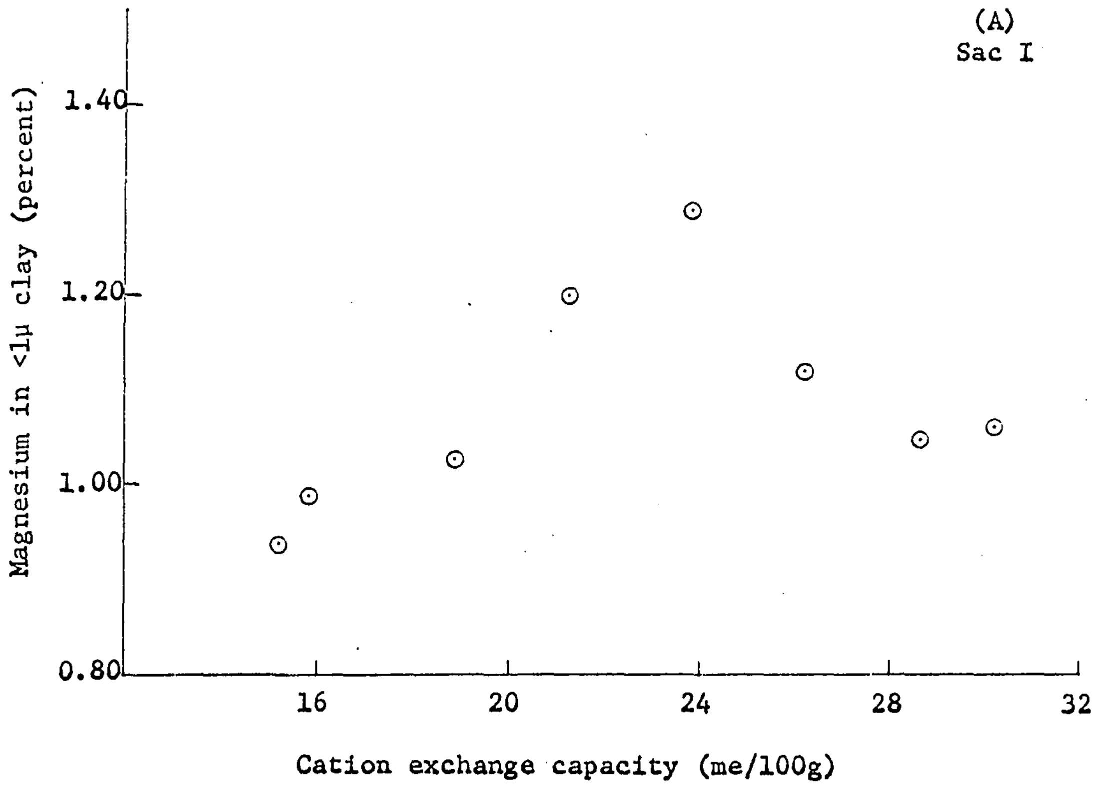

(B)
P739
Magnesium in <1μ clay (percent)
1.20
1.00
0.80
0.60
15
20
25
30
35
<2μ clay (percent)

of a forested soil may be affected some because of the greater acidity and increased leaching in these horizons, but this is not indicated in the soils studied. Magnesium is not a major plant nutrient, and there is not an appreciable difference between the amount recycled by prairie and forest vegetation.

To further explain the magnesium status of these soils the magnesium content is related to some of the other soil properties. The Mg in the $<1\mu$ clay and cation exchange capacity, C.E.C.; the Mg in the $<1\mu$ clay and exchangeable hydrogen, H^+, relationships for the Sac, Dinsdale and Klinger soils are shown in Figures 31-33. Generally the Mg content decreases very gradually with depth. The C.E.C. and H^+ remain uniform in the upper 3 or 4 horizons and then decrease gradually with depth. The C.E.C. and H^+ were determined and reported on whole soil basis, and the values are influenced by the organic matter and clay content. Figure 34 shows the Mg in the $<1\mu$ clay and H^+ for the two Sac and the two Dinsdale profiles. When the values for the profiles are averaged there is a weak inverse relationship, or as the Mg increases, the H^+ decreases. In the lower loess horizon and the upper till horizon the Mg and H^+ relationships do not fit the trend of the upper part of the profile. In the lower loess and till parts of the profile, the H^+ decreases may be caused by decrease in $<2\mu$ clay content. Generally, too, the Mg values are low in the till portion of the profile.

The Mg in the $<1\mu$ clay and percent base saturation relationship for the two Sac profiles is shown in Figure 35 and for the two Dinsdale profiles in Figure 36. The Mg and base saturation relationships in the

Figure 31. Magnesium in the $<1\mu$ clay and cation exchange capacity (A); magnesium in the $<1\mu$ clay and exchangeable hydrogen (B) relationships in Sac I, a well drained prairie soil from northwestern Iowa


(A)
Sac I
Magnesium in <1μ clay (percent)
1.40
1.20
1.00
0.80
16
20
24
28
32
Cation exchange capacity (me/100g)

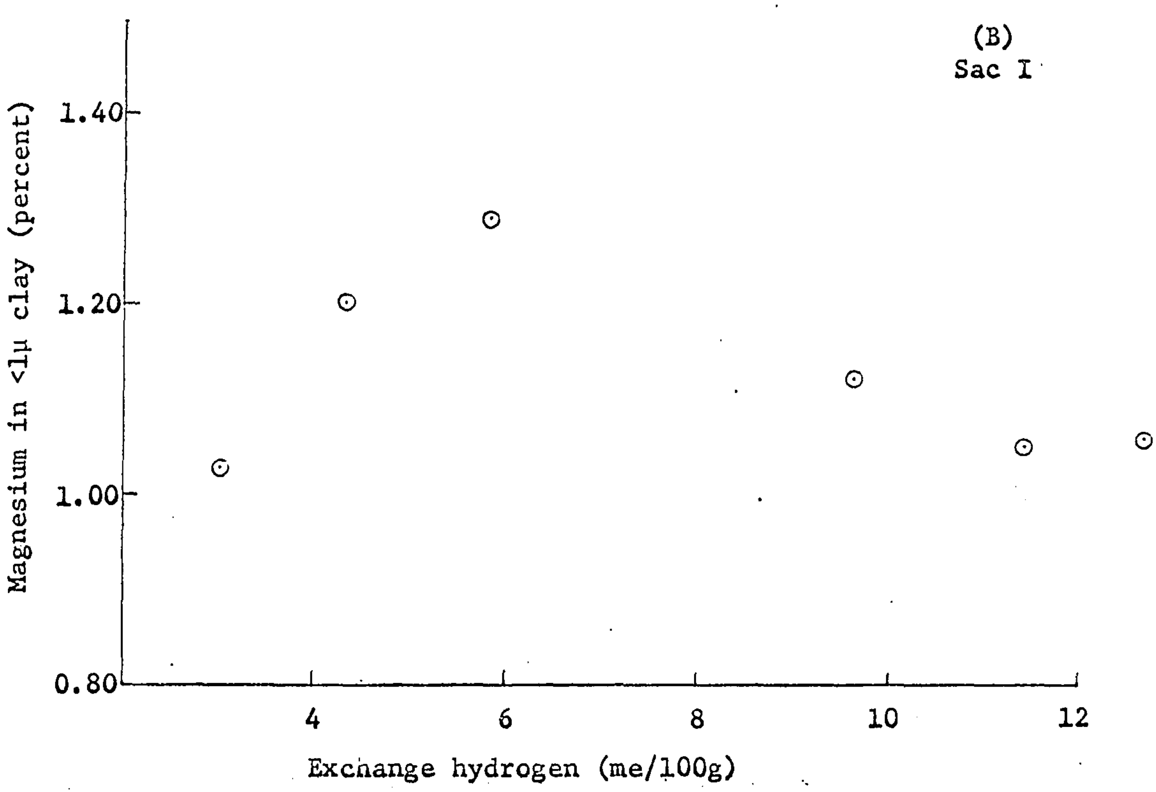
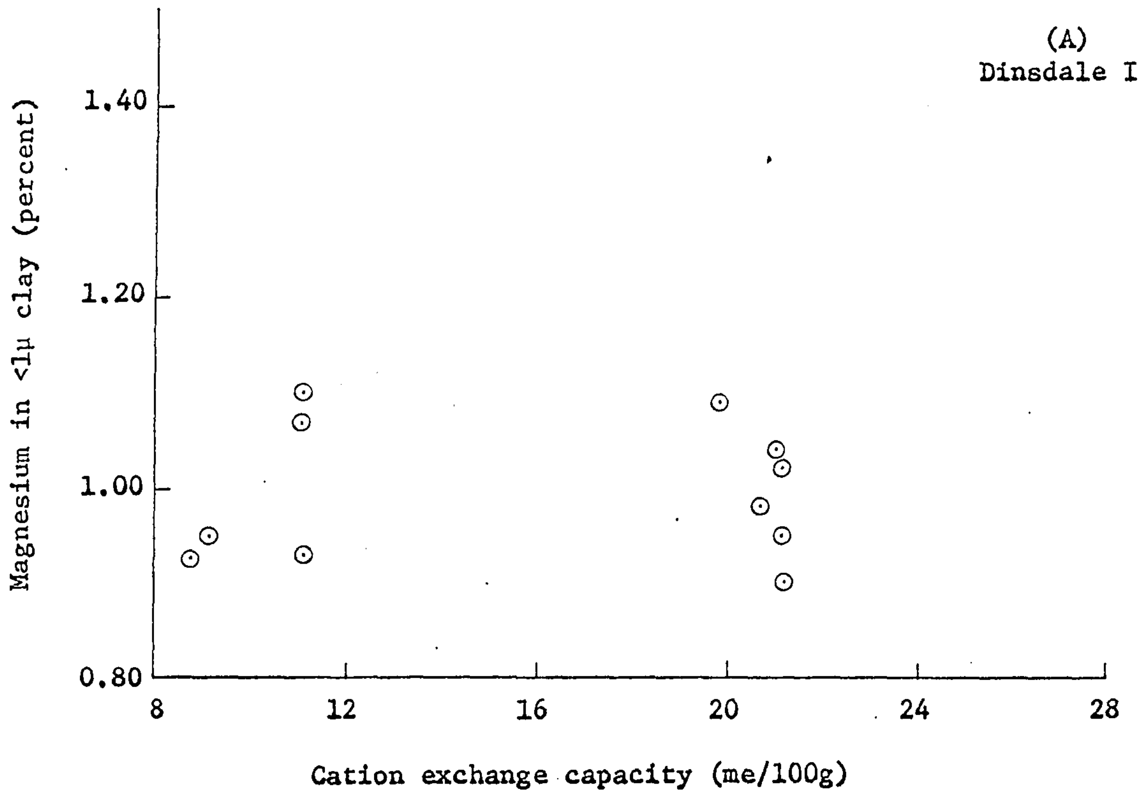

(B)
Sac I
Magnesium in <1μ clay (percent)
1.40
1.20
1.00
0.80
4
6
8
10
12
Exchange hydrogen (me/100g)

Figure 32. Magnesium in the $<1\mu$ clay and cation exchange capacity (A); magnesium in the $<1\mu$ clay and exchangeable hydrogen (B) relationships in Dinsdale I, a well drained prairie soil from eastern Iowa


(A)
Dinsdale I
Magnesium in <1μ clay (percent)
1.40
1.20
1.00
0.80
8
12
16
20
24
28
Cation exchange capacity (me/100g)

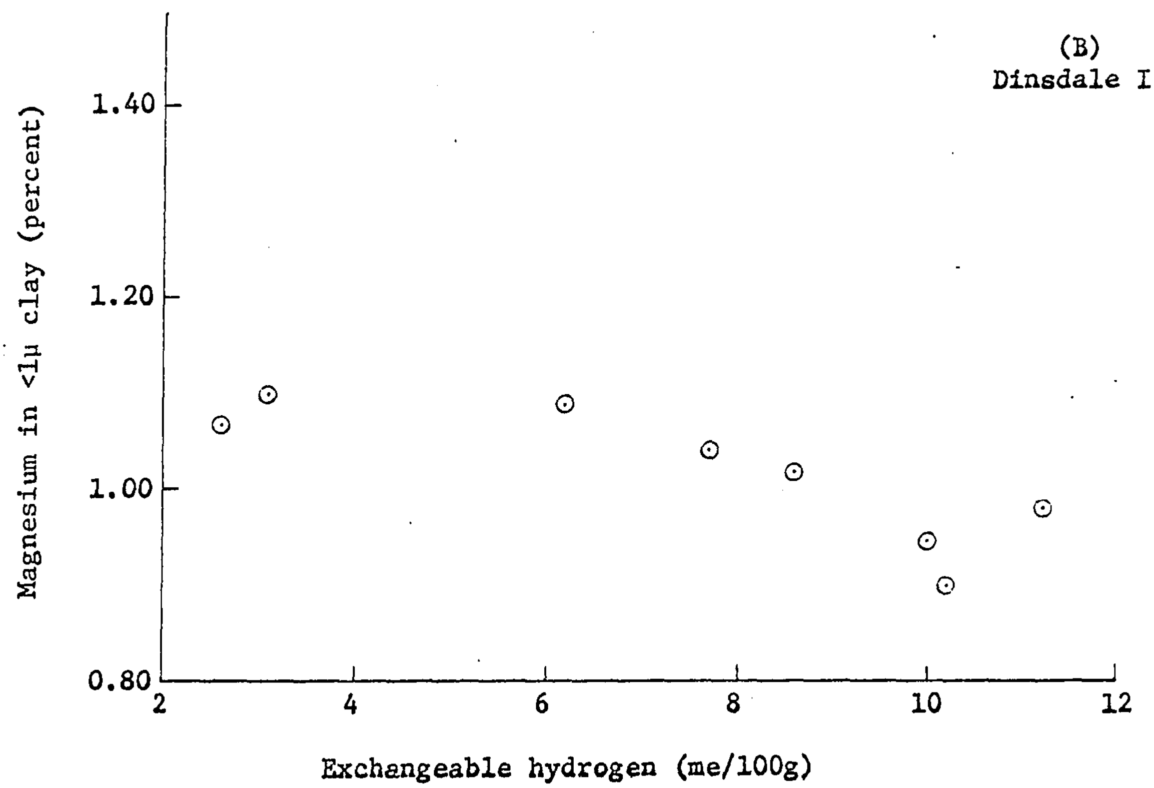
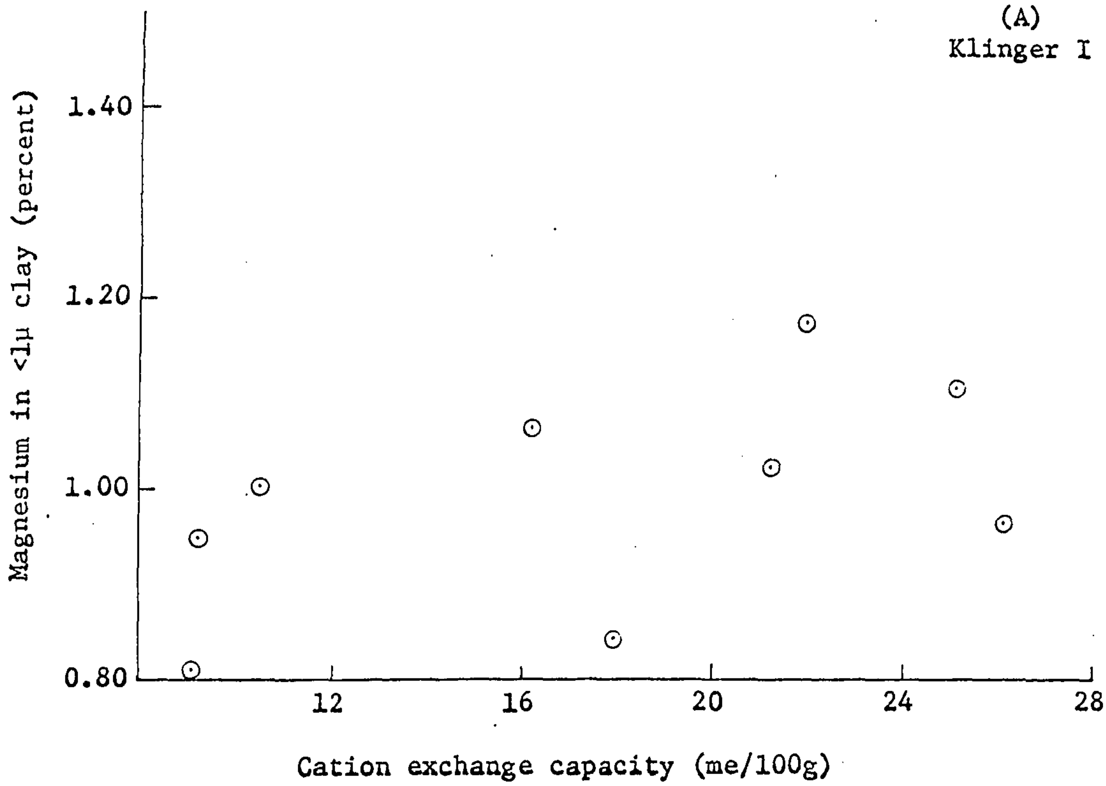

(B)
Dinsdale I
Magnesium in <1μ clay (percent)
1.40
1.20
1.00
0.80
2
4
6
8
10
12
Exchangeable hydrogen (me/100g)

Figure 33. Magnesium in the $<1\mu$ clay and cation exchange capacity (A); magnesium in the $<1\mu$ clay and exchangeable hydrogen (B) relationships in Klinger I, a somewhat poorly drained prairie soil from eastern Iowa


(A)
Klinger I
Magnesium in <1μ clay (percent)
1.40
1.20
1.00
0.80
12
16
20
24
28
Cation exchange capacity (me/100g)

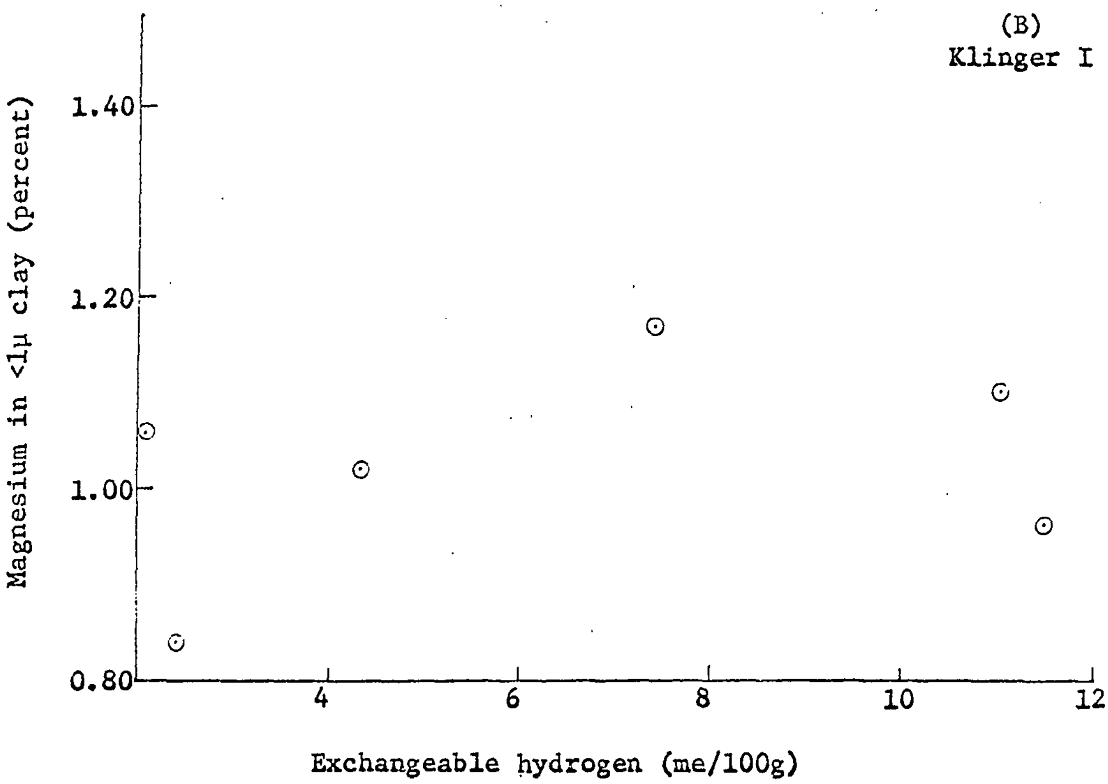

(B)
Klinger I
Magnesium in <1μ clay (percent)
1.40
1.20
1.00
0.80
4
6
8
10
12
Exchangeable hydrogen (me/100g)

Figure 34. Magnesium in the $<1\mu$ clay and exchangeable hydrogen relationships for the two Dinsdale and two Sac profiles

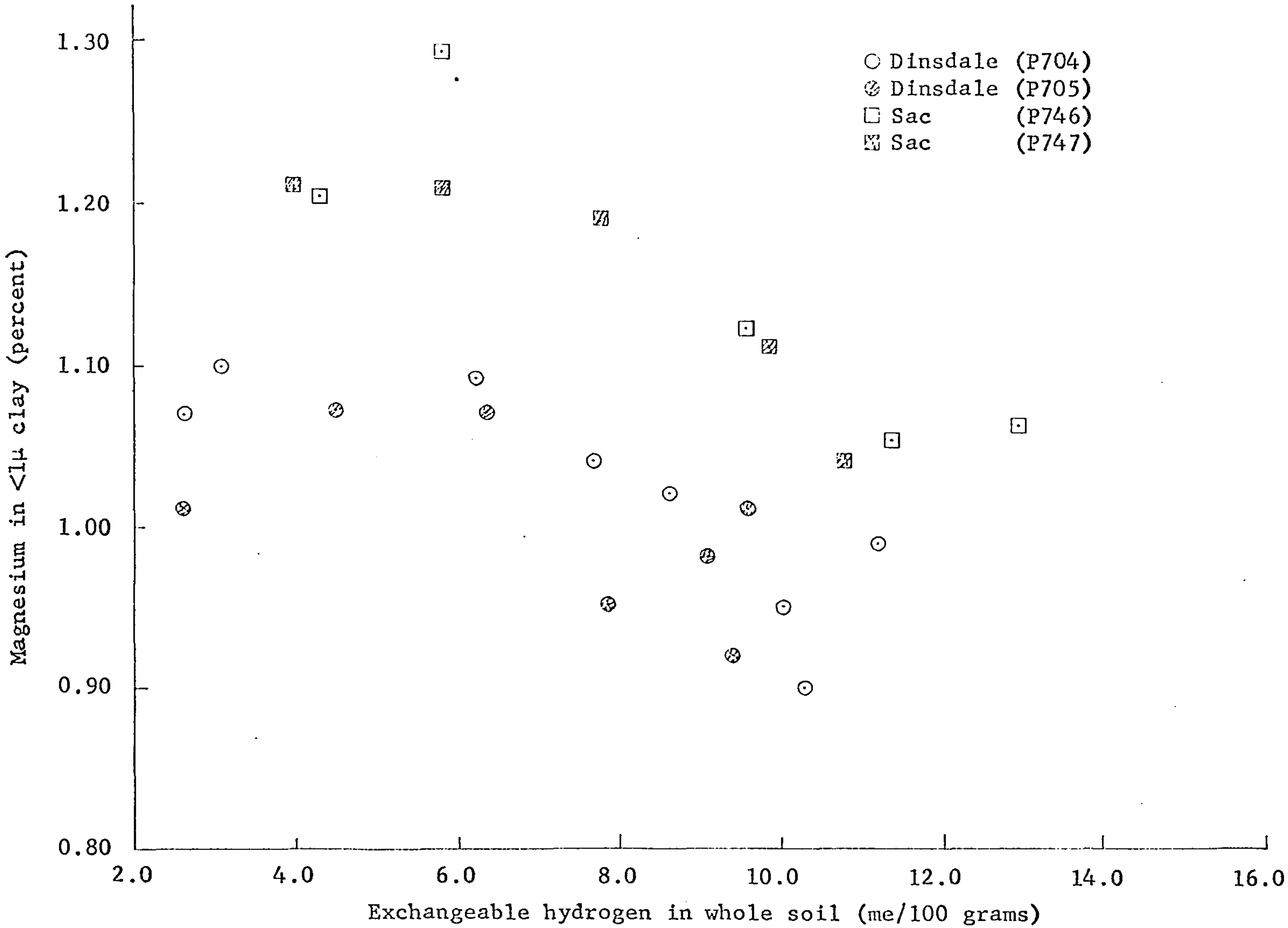
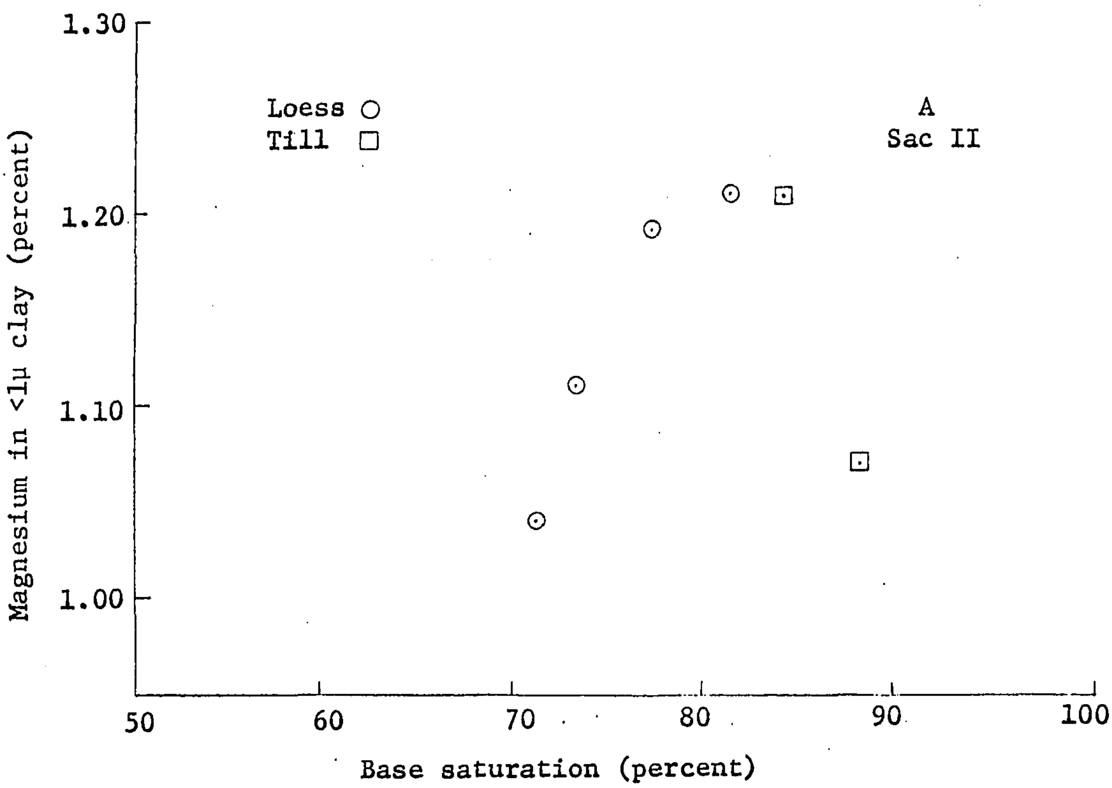

Dinsdale (P704)
Dinsdale (P705)
Sac (P746)
Sac (P747)
Magnesium in <1μ clay (percent)
1.30
1.20
1.10
1.00
0.90
0.80
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
Exchangeable hydrogen in whole soil (me/100 grams)

Figure 35. Magnesium in the $<1\mu$ clay and base saturation relationships for the Sac II (A) and Sac I (B) profiles


1.30
1.20
1.10
1.00
Magnesium in <1μ clay (percent)
Loess
Till
A
Sac II
50
60
70
80
90
100
Base saturation (percent)

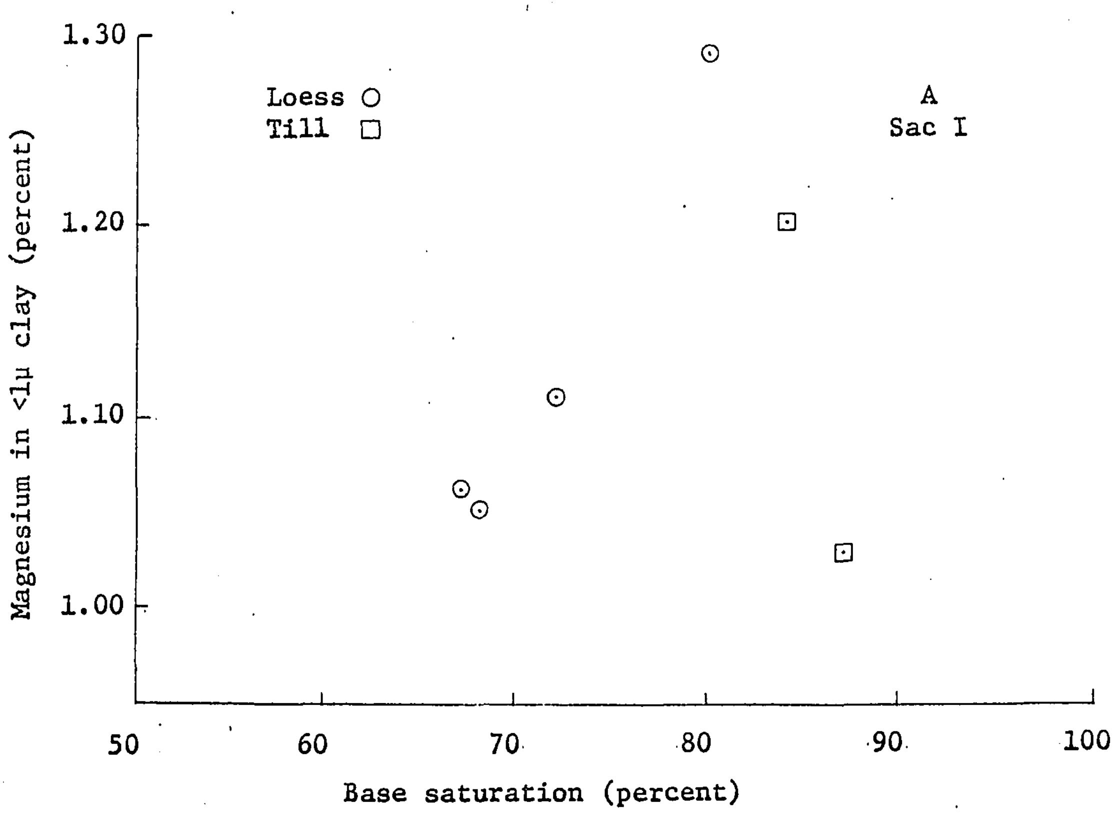
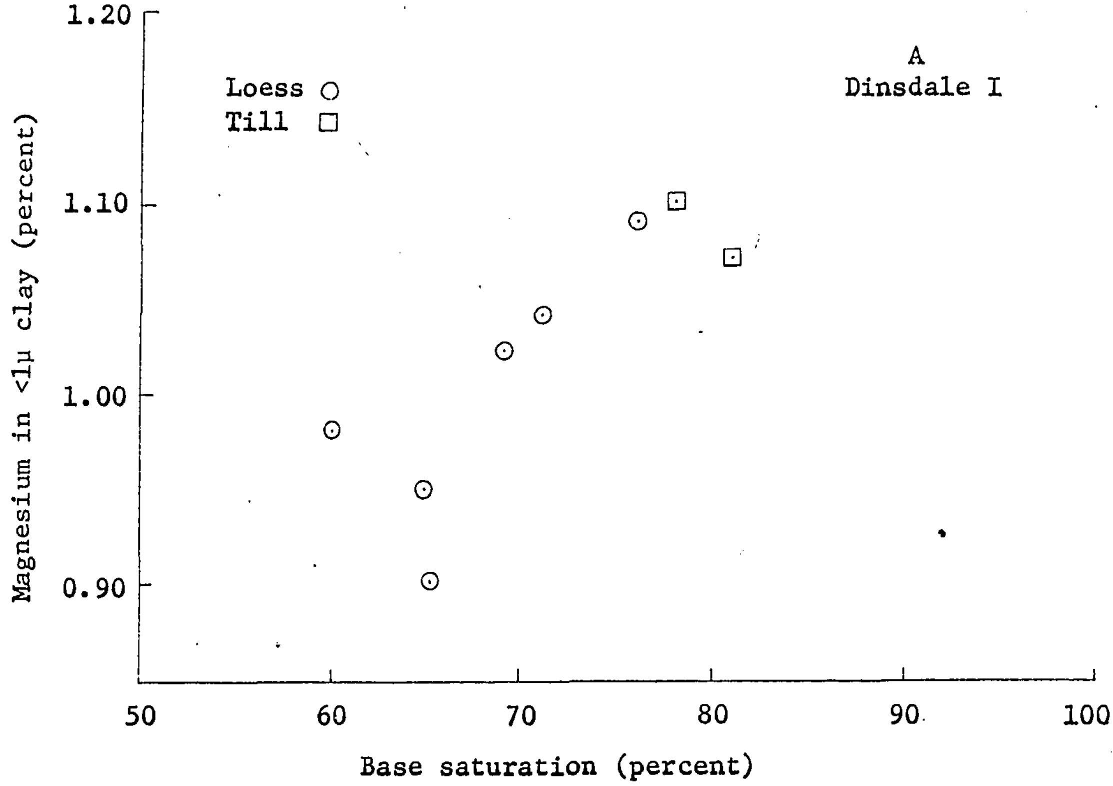

1.30
1.20
1.10
1.00
Magnesium in <1μ clay (percent)
Loess
Till
A
Sac I
50
60
70
80
90
100
Base saturation (percent)

Figure 36. Magnesium in the $<1\mu$ clay and base saturation relationships for the Dinsdale I (A) and Dinsdale II (B) profiles


1.20
1.10
1.00
0.90
Magnesium in <1μ clay (percent)
Loess
Till
A
Dinsdale I
50
60
70
80
90
100
Base saturation (percent)

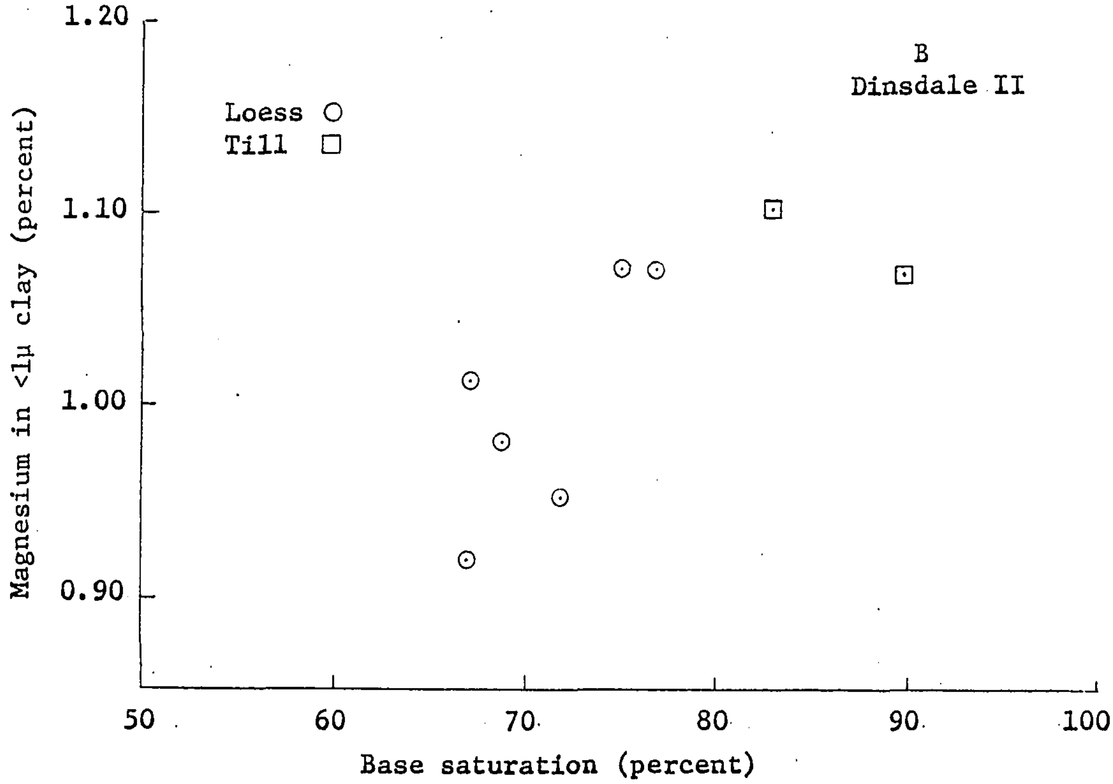

1.20
1.10
1.00
0.90
Magnesium in <1μ clay (percent)
Loess
Till
B
Dinsdale II
50
60
70
80
90
100
Base saturation (percent)

Figure 37. Potassium released with sodium tetraphenylboron (NaTPB) in 7 day period and percent potassium in the $<1\mu$ clay times percent $<2\mu$ clay relationships in all soils analyzed for K release

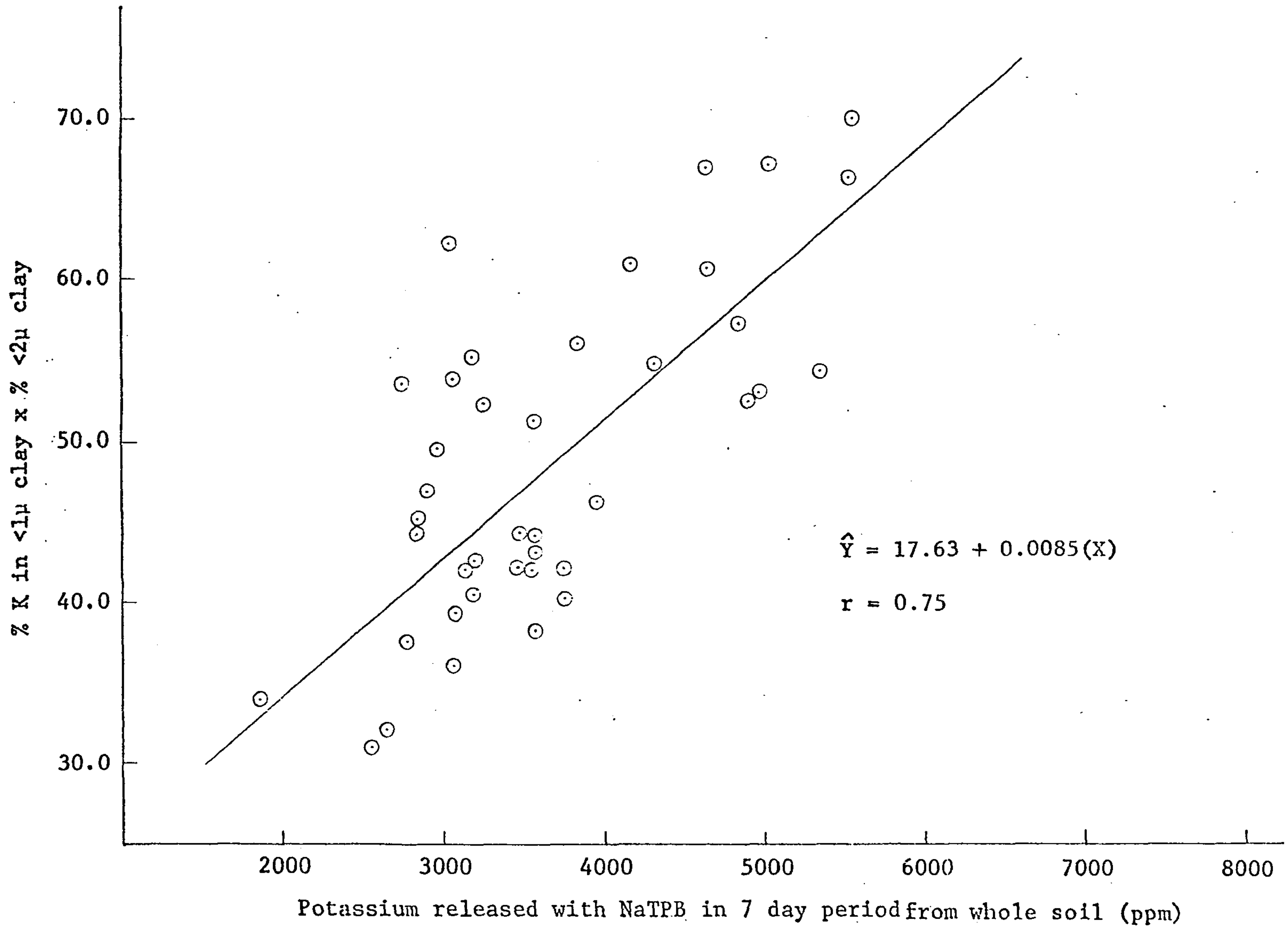
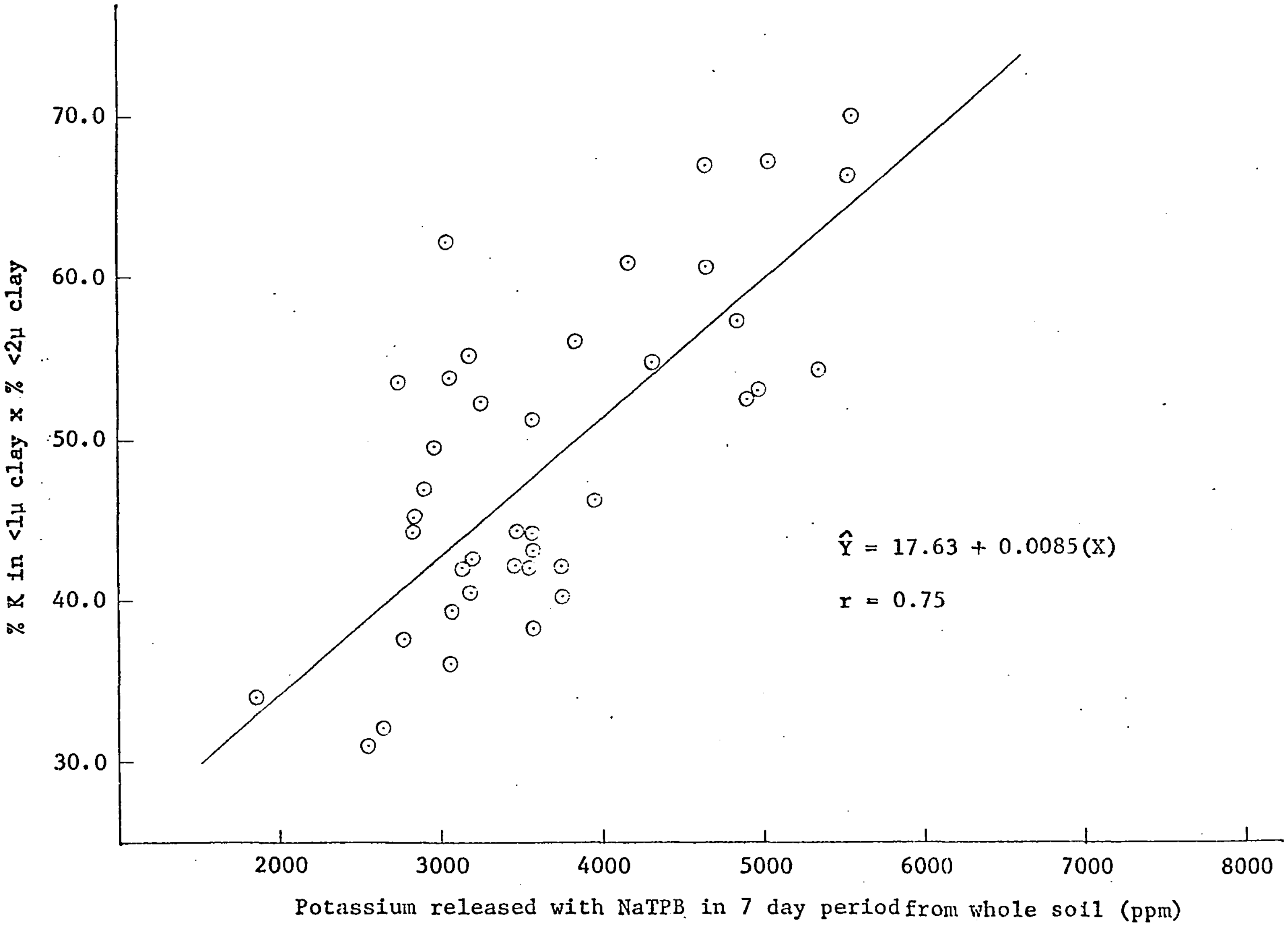

70.0
60.0
50.0
40.0
30.0
% K in <1μ clay x % <2μ clay
2000
3000
4000
5000
6000
7000
8000
Potassium released with NaTPB in 7 day period from whole soil (ppm)
$\hat{Y} = 17.63 + 0.0085(X)$
$r = 0.75$

Figure 38. Potassium released with sodium tetraphenylboron (NaTPB) in 60 day period and percent K in <1μ clay times percent <2μ clay relationships in all soils analyzed for K release


70.0
60.0
50.0
40.0
30.0
% K in <1μ clay x % <2μ clay
2000
3000
4000
5000
6000
7000
8000
Potassium released with NaTPB in 7 day period from whole soil (ppm)
Ŷ = 17.63 + 0.0085(X)
r = 0.75

loess part of the profile show a clear trend; however, the relationship in the lower loess and upper till is quite different, appearing to be separate systems. In the loess portion the Mg increases as the base saturation increases, but the limited number of values in the till portion indicate that the Mg decreases as base saturation increases.

The depth to 1.2 percent Mg is about 15 to 20 inches in the prairie soils of northwest Iowa, but is more than 70 inches in the better drained prairie thin loess/till soils of eastern Iowa (Tables 6 and 12). This is interpreted as indicating more and greater depth of leaching in the latter soils. In the prairie/forest transition soil of northwestern Iowa (Table 12) the depth to 1.2 percent Mg is greater than 60 inches. In the forest influenced thin loess/till soils of eastern Iowa the depth to 1.2 percent Mg is greater than in the prairie sequence member. This indicates leaching is greater under forest than under prairie vegetation.

Nonexchangeable magnesium is primarily a part of the octahedral layer of clay minerals. This is not an exchange position and apparently the Mg is released from the octahedral coordination along with other ions as H^+ attacks the clay presumably at the edges and gradually breaks down the clay lattice as discussed by Kerr _et al_. (1956), Osthaus (1956), Caillere and Henin (1965) and Jackson _et al_. (1948, 1952). Studies by Bray (1936, 1937) and Brown _et al_. (1936) primarily on Illinois and Nebraska loess-drained soils indicate that Mg content of the clay fraction decreases as stage of textural development increases. Barshad (1960b) has indicated that Mg content of the clay fraction can be expected to decrease as base saturation or exchangeable Ca/Mg ratios decrease. Based on the results of the present study in soil formation under acid conditions Mg apparently is depleted from the clay fraction (Table 13). This depletion is greater in the part of the profile with the lowest base saturation. As base saturation usually decreases with depth, the Mg content of the clay fraction would be expected to increase with depth.

The nonexchangeable magnesium status as determined in this study is in agreement with the work of Protz (1965) and shows the same relationships as found for exchangeable magnesium by other investigators. The Mg content of the $<1\mu$ clay of the thin loess/till soils is higher in northwestern Iowa than in eastern Iowa. The difference in Mg content is approximately the same as the difference in K content of the soils from the two areas. The Mg also has a characteristic profile distribution, but the difference between maximum and minimum content in the profile is not as pronounced as the K relationship. The Mg status of the thin loess/till soils is recommended as a criterion for classification at the series level in addition to the morphological and clay distribution characteristics.

Table 13. Exchangeable calcium/magnesium ratios and nonexchangeable magnesium data for selected soils

Soil and profile number	A horizons[a]		B horizons[a]	
	Ca/Mg ratio	% Mg	Ca/Mg ratio	% Mg
Sac I (P746)[b]	3.4	1.05	2.7	1.20
Sac II (P747)[b]	3.3	1.08	2.7	1.20
Dinsdale I (P704)[b]	2.8	0.94	2.5	1.05
Dinsdale II (P705)[b]	2.9	0.98	2.4	1.03
Tama (86-1)[b]	2.9		2.2	
Tama (P27)[c]	2.8		2.2	
Galva (P248)[d]	2.3		2.0	
Primghar (21-4)[b]	2.4		1.8	

[a]Average of all subhorizons.

[b]Data from U.S. Soil Survey Staff (1966).

[c]Data from Corliss (1958).

[d]Data from Foth and Riecken (1954).

Clay Mineralogy and Soil Formation

Generally the northwestern Iowa soils have a greater proportion of illite to montmorillonite than the eastern Iowa soils, even though montmorillonite is the dominant clay mineral in the solum of the soils of both areas. The kaolinite is generally low in both areas, but the eastern Iowa soils have a slightly higher amount than those from the northwestern part of the state. These trends are evident in the profile distribution of montmorillonite/kaolinite (M/K) and montmorillonite/illite (M/I) ratios as shown in Figure 22. The Sac soil has very similar M/K and M/I ratios and the maximum values are nearer the surface than in the Dinsdale. The Dinsdale has a higher M/I ratio than M/K ratio and the difference is most pronounced in the B horizon. Both the M/K and M/I ratios are similar for both the Sac and Dinsdale soils in the lower horizons below about 30 inches, the top of the till.

Montmorillonite is the dominant clay mineral and illite is next most abundant in the thin loess/till soils of Iowa. Generally the montmorillonite intensity (peak area) increases with depth in the loess portion, but decreases abruptly in the loess-till contact horizon (see Figures 20-22). Based on peak area there is a relatively greater amount of montmorillonite than $<2\mu$ clay in the B horizon (Table 14). The Dinsdale soils have larger B/A horizon ratios in both clay and montmorillonite peak areas. One explanation is that montmorillonite has moved preferentially from the A to the B horizon both in the Sac and Dinsdale profiles, but more in the latter. However, the Sac soil has a low B/A horizon clay ratio indicating little movement of clay, but the Dinsdale soil has a low ratio also. Another explanation may be in the better crystallinity of the montmorillonite in the B horizon, disproportionately affecting the peak area. The montmorillonite intensity increases slightly in the upper 2 or 3 till horizons, but then becomes uniform with depth.

The illite intensity generally decreases with depth in the loess portion and gradually increases in the till portion of the profile, but becomes uniform in the lower till horizons. In the upper horizons of

Table 14. Summary of B/A horizon ratios of montmorillonite peak areas, illite peak areas and <2μ clay for the Sac and Dinsdale soils

	1	2	3	4	5
Soil and profile number	B/A horizon montmorillonite peak area ratio	B/A horizon illite peak area ratio	B/A horizon clay ratio	Ratio 1/3[a]	Ratio 2/3[a]
Sac I (P746)	$\frac{315}{108} = 2.9$	$\frac{5}{6} = 0.8$	1.02	1.8	0.8
Sac II (P747)	$\frac{249}{139} = 1.8$	$\frac{5}{7} = 0.7$	1.03	1.7	0.7
Dinsdale I (P704)	$\frac{311}{77} = 4.0$	$\frac{4}{8} = 0.5$	1.14	2.7	0.5
Dinsdale II (P705)	$\frac{350}{66} = 5.3$	$\frac{5}{5} = 0.8$	1.14	4.6	0.7

[a]Ratios of column 1 to column 3 and column 2 to column 3.

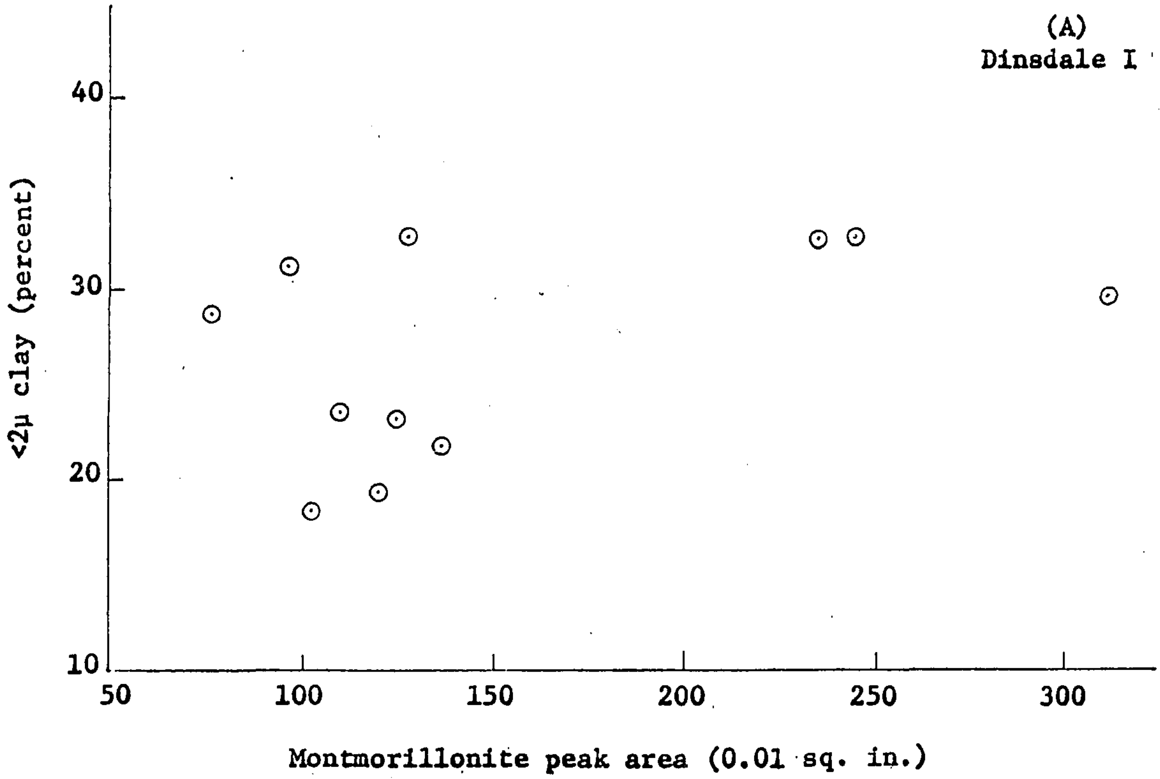
the loess portion of the profile illite may be present in the coarse clay fractions and such fractions do not leach appreciably. If montmorillonite leaches preferentially, the illite could become more concentrated. However, as discussed earlier, K is recycled by plants to the surface horizons, and this could account for the greater illite peak areas. The illite content increases with depth in the till portion probably because the degree of weathering and conversion of illite to other clay minerals is decreasing.

In the till portion of the profiles the illite peak areas increase relative to the montmorillonite peak areas (see Figures 20-22). As mentioned earlier the till has a higher K content in the <1μ clay fraction than the loess portion of the profiles. The Sac soils have slightly less difference in illite peak areas between the A and B horizons than the Dinsdale soils (Table 14). The minimum illite intensities occur in the B horizon where the montmorillonite peak areas are at a maximum for both the Sac and Dinsdale profiles (Figures 20 and 21).

Based on the hypothesis that illite weathers to montmorillonite the data discussed above indicate that the northwestern Iowa soils are less weathered and that weathering is proceeding more slowly than in comparable soils from the eastern part of the state. Since it is assumed that originally the sediments were similar, and that the soils have been forming for approximately the same time, the difference is attributed to the higher annual precipitation in the eastern part of the state.

The illite peak area (relative intensity) is directly related to the K content of the <1μ clay fraction of all soils x-rayed, except the Klinger profile (Figures 23-25). The correlation coefficient for this relationship is 0.91 for the Dinsdale profile and 0.98 for the Sac profile. This is in accord with the hypothesis that K is primarily in the illite clay mineral. The montmorillonite peak area and <2μ clay relationships for the Dinsdale and Sac soils are shown in Figure 39 and the magnesium in the <1μ clay fraction versus montmorillonite and illite peak area relationship is given in Figure 40. Both of these relationships apparently do not have any definite trends. The weathering and

Figure 39. Less than 2μ clay and montmorillonite peak area (0.01 sq.in.) relationships in Dinsdale I (A) and Sac I (B); well drained prairie soils from eastern and northwestern Iowa


(A)
Dinsdale I
40
30
20
10
<2μ clay (percent)
50
100
150
200
250
300
Montmorillonite peak area (0.01 sq. in.)

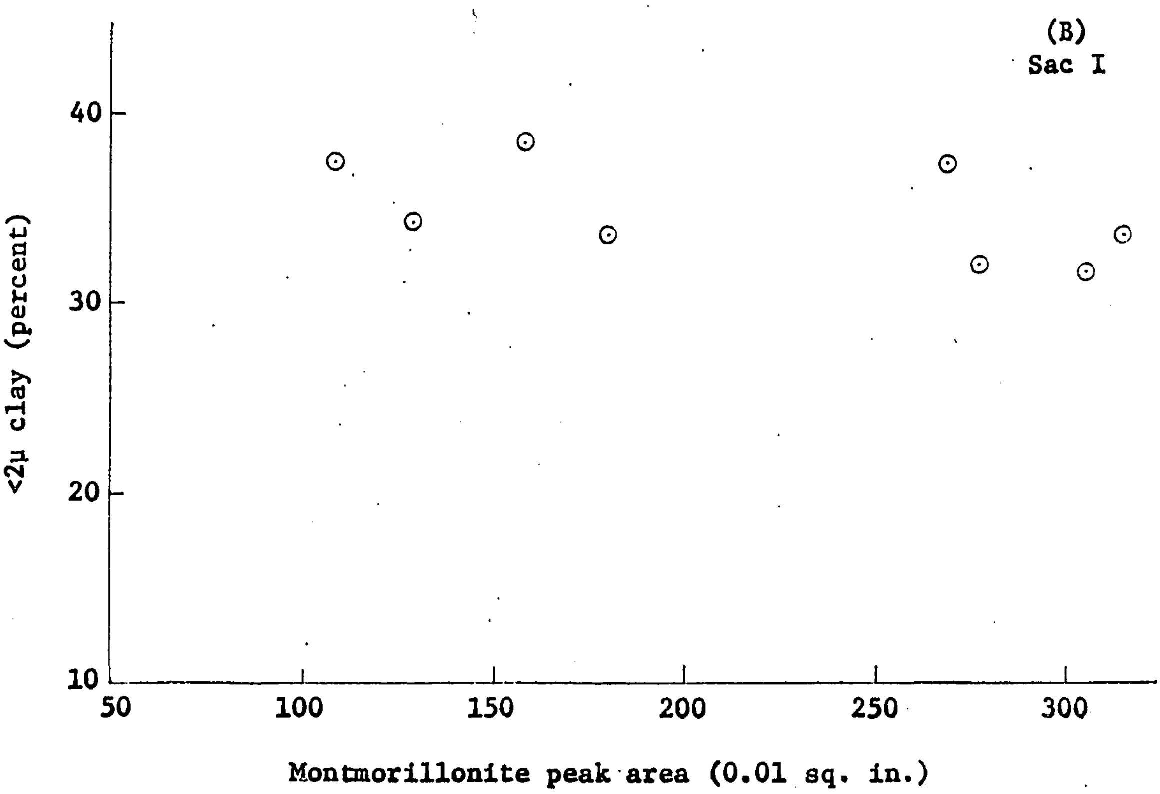
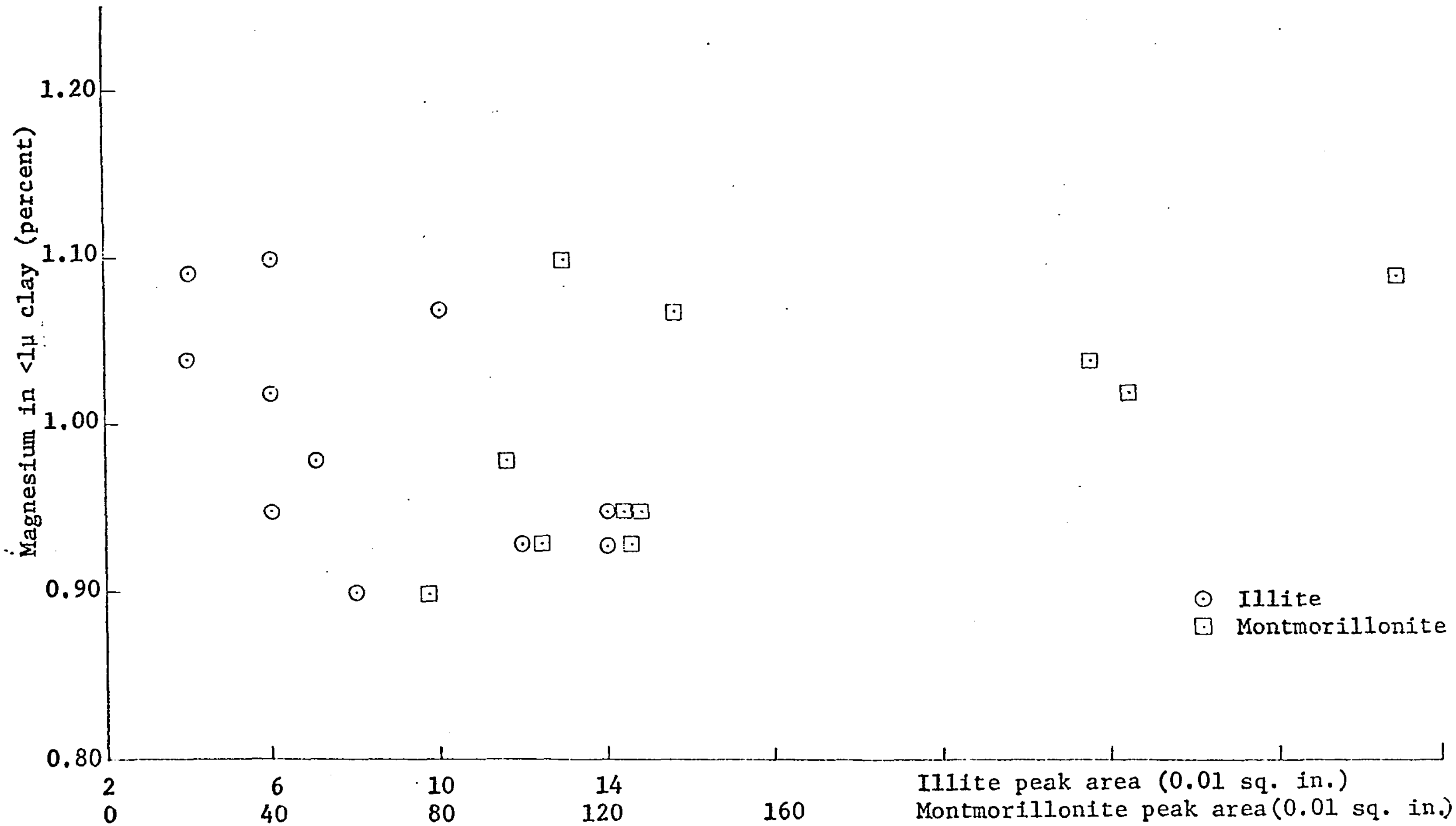

(B)
Sac I
40
30
20
10
<2μ clay (percent)
50
100
150
200
250
300
Montmorillonite peak area (0.01 sq. in.)

Figure 40. Magnesium in the $<1\mu$ clay, and the montmorillonite and illite peak area (0.01 sq.in.) relationships for Dinsdale I, a well drained prairie soil from eastern Iowa


Magnesium in <1μ clay (percent)
1.20
1.10
1.00
0.90
0.80
2
0
6
40
10
80
14
120
160
Illite peak area (0.01 sq. in.)
Montmorillonite peak area (0.01 sq. in.)
Illite
Montmorillonite

alteration of the clay minerals appears to be a separate and distinct process which is affected by, but not directly dependent on the processes affecting the content and distribution of the <2μ clay in the soil profiles studied.

The data of this study indicate that the clay mineralogy and the K and Mg content in the soils studied are interrelated. Apparently these constituents are parts of separate systems in the soil profile, but the related soil forming processes are dependent on each other and on the profile clay distribution. Both the amount of clay and the B/A horizon clay ratio affect physically and chemically the leaching and recycling of the K and Mg and the weathering and alteration of the clay minerals. There is a relatively greater accumulation of montmorillonite than clay in the B horizon and the montmorillonite probably moves downward preferentially; however, the maximum montmorillonite is in the B horizon where the clay is also maximum. The K and Mg ions are both primary ions in clay minerals, but the position occupied and behavior of the K ion is different from the Mg ion. The K is an interlayer cation in micaceous clay minerals and can be removed by weathering without breakdown of the layer lattice. Several investigators (Jackson _et al_., 1948, 1952; Johnson and Jeffries, 1957; Scott and Reed, 1962b and White, 1950) have postulated that as weathering proceeds in relatively unweathered sediments that contain micaceous minerals, the interlayer K is lost as a first step during the conversion of illite to montmorillonite. After the K is removed, the illite becomes expandable as water and/or other, primarily divalent, cations may enter the interlayer positions. These changes proceed through several stages and are dependent on factors such as particle size distribution, nature of the materials, moisture, acidity, temperature, oxidation-reduction conditions and the length of time the processes have been in action.

The magnesium ion may be in the interlayer position of clay minerals in an exchangeable form, but the nonexchangeable form, Mg, is a part of the octahedral layer lattice. Apparently the Mg is released from the octahedral position along with other ions that make up the lattice as H^+ attacks the clay, primarily at the edges, and gradually breaks down the lattice as discussed by Kerr et al. (1956), Caillere and Henin (1965) and Osthaus (1956). If genetic clay formation is occurring in the B horizon, it apparently is not a magnesium-clay because there is no accumulation of Mg in this horizon. Magnesium is not readily reverted from the exchangeable to nonexchangeable form by clay, so downward leaching is the primary process affecting magnesium.

Differentiation of the Thin Loess/till Soils of Iowa

Many theories concerning the genesis of soils have been advanced. Simonson (1959) postulates that soil genesis consists of two overlapping steps, the accumulation of parent materials and the differentiation of horizons in the profile. The horizon differentiation is of immediate concern to soil scientists and consists of additions, removals, transfers and transformations within the soil system. Cline (1961) states that physical, chemical and biological processes are all contributors to development of soil, but their rates differ in various environments and with time the soil changes mainly in degree of expression of properties rather than in kind. However, as the soil itself, or the environment changes, the course of soil formation may be expected to shift and produce new sets of properties. McCaleb (1959) states that morphological changes occur step-wise in response to differences in physical, chemical and biological environments in time, and that soils differ in degree and intensity of expression of horizon sequences due primarily to environmental differences. In the present study an attempt is made to explain the genesis of the thin loess/till soils of Iowa and to differentiate between the soils from the northwestern and eastern parts of the state.

The thin loess soils are a characteristic group which is forming in 20 to 40 inches of Wisconsin loess over glacial till. In Iowa these soils occur in the northwestern and eastern parts of the state. Evidence from the current and previous studies indicates that the parent material from which these soils are forming is very similar in both areas and of approximately the same geological age. The average annual precipitation in the northwestern area is about 26 to 28 inches, and in the eastern area it is approximately 32 to 34 inches. The temperature difference is probably negligible. The topography of the soils studied is level to gently sloping, and all three drainage classes occur in both areas. Prairie/forest transition soils are of minor importance in both areas and a forested soil is recognized in the eastern area. By comparing soils with similar drainage classes and like vegetation the effects due to precipitation differences can be evaluated between the two areas.

Morphologically the soils of the two areas appear similar; although, the northwestern Iowa soils have a slightly finer texture in the surface horizons and the depth to the maximum clay horizon is less than in the eastern Iowa soils. Because of this similar morphology and parent material there has been a question concerning the validity of the separation of the Sac and related soils of northwestern Iowa from the Dinsdale and related soils of eastern Iowa at the series level. According to data presented in this study the Sac and related soils of northwestern Iowa have a higher nonexchangeable potassium and magnesium content, release more potassium with sodium tetraphenylboron, and have greater montmorillonite/illite and montmorillonite/kaolinite ratios in addition to being less developed than the Dinsdale and related soils of eastern Iowa. Similar differences are present between the other members of the Sac and Dinsdale sequences; another example would be a comparison of the poorly drained counterparts, Maxfield and P738. This indicates that the eastern Iowa soils are weathered to a greater degree and are weathering at a greater rate than the northwestern Iowa soils. Since the other soil forming factors are constant, this difference is attributed to the higher annual precipitation in the eastern part of the state. This constitutes a firmer basis on which the Sac and related soils may be separated from the Dinsdale and related soils.

From a practical viewpoint the separation of the northwestern and eastern Iowa soils may be substantiated on the nutrient supplying potential of these soils. The Sac and related soils are less weathered, and not only have a higher nutrient content, but should maintain this characteristic for a longer period of time because of the less weathered condition. The nutrients are made available more slowly in the northwestern area due to less rainfall, and a greater percentage is used by plants before they are leached.

Selected thin loess/till soils from eastern Illinois and southwestern Ohio that are considered similar in age to the Iowa soils were analyzed for comparison. The average annual precipitation is 37 to 39 inches in eastern Illinois area and 39 to 41 inches in the southwestern Ohio area. All drainage and vegetation classes are recognized. These soils are morphologically similar to the Iowa thin loess soils, but they are more developed as evidenced by the greater B/A horizon clay ratios and the depth to the maximum clay horizon. The data in this study indicate that the Illinois and Ohio soils are more developed, and have a similar nonexchangeable potassium and magnesium contents in the upper part of the profile, but much higher contents, especially K, in the substratum than do the Iowa counterparts. The Illinois and Ohio soils are weathered to a greater degree and are weathering at a greater rate than the Iowa soils as indicated by the NaTPB extractable K and x-ray diffraction data. Since the other soil forming factors are considered constant, the differences in the Illinois soils are attributed to the higher annual precipitation than Iowa. These differences constitute a firmer basis for the separation of the Iowa soils from the Illinois and Ohio soils at the series level.

SUMMARY AND CONCLUSIONS

A study of the thin loess/till soils of Iowa was conducted to gain a better understanding of these soils and to establish a firmer basis for their classification at the series level. Associated soils from different parent materials and similar thin loess soils from Illinois and Ohio are analyzed for comparison.

The thin loess soils are a recently separated group of characteristic soils that is forming in 20 to 40 inches of Wisconsin loess over glacial till. These soils occur in northwestern Iowa in a 26 to 28 inch annual precipitation area and in eastern Iowa in a 32 to 34 inch rainfall area. The parent materials are similar and are considered to be approximately the same age in both areas. All three drainage classes occur in both areas, and prairie vegetation was predominant, but prairie/forest transition soils are recognized.

Data indicate that the Sac and related soils of northwestern Iowa are less developed, have a higher nonexchangeable potassium and magnesium content, release more potassium with NaTPB and have a higher illite content than the Dinsdale and related soils of eastern Iowa. These differences attributed to the less weathered condition of the northwestern Iowa soils are apparently due to the lower annual precipitation in that area. The poorly drained soils are generally less weathered than the well drained associates and this condition is more pronounced in the eastern Iowa soils. A forested thin loess/till soil is not recognized in northwestern Iowa; however, the prairie/forest transition member is less weathered than the eastern Iowa transition soils. In the eastern area the forested soil is slightly more weathered than the prairie soil. The loess portion of these soils is similar to the thick loess soils (Tama sequence), but the till portion is more like the surficial sediment soils (Kenyon sequence). The Iowa thin loess/till soils are weathered and developed to a greater degree than the upper loess portion of the Illinois and Ohio counterparts, but the two groups of soils have a similar K and Mg content. However, the till portion of the Illinois and Ohio soils has a much higher K content and a slightly higher Mg content. The more weathered condition of the Illinois and Ohio soils is attributed to the higher annual precipitation, and the higher K and Mg content is attributed to a higher content of these ions in the parent material.

The differences in characteristics of the northwestern and eastern Iowa soils are recommended as a basis for separation of the Sac and related soils from the Dinsdale and related soils at the series level. The less developed and less weathered condition and the lower K and Mg content of the lower horizons of the Iowa thin loess soils is a basis for separation of these soils from the thin loess soils of Illinois and Ohio.

More specifically it may be concluded from the data of this investigation that:

1. Nonexchangeable potassium and magnesium decrease from west to east across the region studied as the degree of weathering and development of the soils increases. Since the parent materials are assumed to have been originally similar, these differences are attributed to the increase in annual precipitation from west to east.

2. The profile distribution of K and Mg is dependent on the leaching

and recycling processes, but the rates are controlled by the rate of conversion from the nonexchangeable form of these ions and the assimilation by plants.

3. Climate is the primary factor which affects the K and Mg status, but the poorly drained soils and forested soils have a higher K and Mg content than their opposites. The content of these ions in the parent material also determines the present content in the soils.

4. The amount of NaTPB extractable K and illite peak area are directly related to the nonexchangeable potassium content, but the montmorillonite peak area does not appear to have a definite relationship to the $<2\mu$ clay, K or Mg.

5. The greater degree of development and lower K and Mg content of the Dinsdale and related soils of eastern Iowa is recommended as a basis for separation of these soils from the Sac and related soils of northwestern Iowa. The greater degree of development and weathering of the Illinois and Ohio soils along with the higher K and Mg content of the parent material is a basis for separation of these soils from the Iowa soils.

This study has pointed out some of the more important characteristics of the thin loess soils, but many other aspects concerning these soils need to be studied in detail. It is hoped that this study will provide a background for further investigation of the thin loess/till soils.

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APPENDIX A: PROFILE DESCRIPTIONS

Franklin silt loam (P730)

Location: 100 feet west and 440 feet north of the southeast corner of the NE¼ sec. 28, T 84 N, R 6 W, Linn County, Iowa.

Slope and physiographic position: 1 percent, broad, slightly convex ridgetop.

Described by: J. A. Kovar and J. D. Highland, August 1964.

Horizon	Depth	Description (moist Munsell colors)
A1p	0-6"	Black (10YR 2/1) crushes to very dark grayish brown (10YR 3/2), dry color 10YR 5/1; silt loam; weak coarse subangular blocky structure breaking to fine granular; friable; many fine and medium roots; pH 6.8[1]; abrupt smooth boundary.
A12	6-9"	Same as above except weak fine granular structure; pH 6.8; abrupt smooth boundary.
A2	9-16"	Very dark grayish brown (10YR 3/2) with some mixing of dark yellowish brown (10YR 4/4), kneaded 10YR 3/2; light silty clay loam; weak medium platy structure breaking to weak fine subangular blocky; friable; few thin discontinuous light brownish gray (10YR 6/2) grainy silt coatings on horizontal ped faces when dry; few fine soft dark reddish brown (5YR 2/2) Mn oxide concretions; many fine and medium roots; pH 5.5; gradual smooth boundary.
B1	16-22"	Dark grayish brown (10YR 4/2) with few fine faint olive brown (2.5Y 4/4) mottles, crushes to 10YR 4/2, few discontinuous very dark grayish brown (10YR 3/2) grainy silt coatings on peds when moist and light brownish gray (10YR 6/2) when dry; silty clay loam; moderate fine subangular blocky structure with some tendency to weak medium platy; friable; many fine and medium roots; pH 5.1; gradual smooth boundary.
B21	22-32"	Very dark grayish brown (2.5Y 3/2) exteriors and dark grayish brown (2.5Y 4/2) interiors with few fine faint yellowish brown (10YR 5/8) and light olive brown (2.5Y 5/6) mottles, kneaded grayish brown

[1]All pH readings for this study were made with a glass electrode pH meter.

(1Y 5/2); few thin discontinuous light brownish gray (10YR 6/2) grainy silt coatings on peds when dry; silty clay loam; moderate fine and medium subangular blocky structure; friable; few fine soft dark reddish brown (5YR 2/2) Mn oxide concretions; few fine and medium roots; pH 5.3; abrupt wavy boundary.

IIB22	32-42"	Dark grayish brown (10YR 4/2) nearly continuous silt coatings on prism faces (2.5Y 6/2) dry interiors mottled 40% grayish brown (2.5Y 5/2), 30% olive yellow (2.5Y 6/6) and 30% yellowish brown (10YR 5/8), kneaded yellowish brown (10YR 5/6); loam; moderate medium prismatic structure breaking to medium and fine subangular blocky; slightly firm; some grayish brown (2.5Y 5/2) gritty clay between peds and in root channels; common fine dark reddish brown (5YR 2/2) and few fine dark brown (7.5YR 3/2) Mn oxide concretions; coarse sand lens at top of horizon; pH 5.6; gradual smooth boundary.
IIB3	42-49"	Mottled 40% grayish brown (2.5Y 5/2), 40% yellowish brown (10YR 5/8), and 20% olive yellow (2.5Y 6/6), kneaded brownish yellow (10YR 6/6); heavy loam; weak medium prismatic breaking to weak medium and fine subangular blocky structure; slightly firm; some very dark grayish brown (10YR 3/2) clay concentrations in cracks and root channels; few fine soft dark reddish brown (5YR 2/2) Mn oxide concretions; pH 6.1; gradual smooth boundary.
IIC1	49-68"	Mottled 50% yellowish brown (10YR 5/8), 30% light brownish gray (2.5Y 6/2), and 20% light olive brown (2.5Y 5/6), kneaded brownish yellow (10YR 6/6); heavy loam; massive; slightly firm; dark yellowish brown (10YR 4/4) medium sand lens from 54 to 55 inches; few fine very dark reddish brown (5YR 2/2) Mn oxide concretions; pH 6.8; abrupt wavy boundary.
IIC2	68-90"	Mottled 60% yellowish brown (10YR 5/6), 20% light brownish gray (2.5Y 6/2) and 20% light olive brown (2.5Y 5/6), kneaded yellowish brown (10YR 5/8); sandy loam; massive; friable to firm; several thin yellowish brown (10YR 5/8) fine sand lenses; calcareous with few fine soft $CaCO_3$ concretions; pH 8.0; diffuse boundary.

IIC3	90-110"+	Mottled 80% yellowish brown (10YR 5/6) and 20% light brownish gray (2.5Y 6/2), kneaded yellowish brown (10YR 5/8); sandy loam; massive; friable to firm; several thin yellowish brown (10YR 5/8) fine sand lenses; calcareous; pH 8.1.

Franklin silt loam (P731)

Location: Approximately 1600 feet north and 840 feet west of the southeast corner of sec. 12, T 81 N, R 9 W, Iowa County, Iowa.

Slope and physiographic position: 1 percent, slightly convex ridgetop.

Described by: J. A. Kovar and J. D. Highland, August 1964.

Horizon	Depth	Description (moist Munsell colors)
A1p	0-8"	Very dark gray (10YR 3/1) crushes to very dark grayish brown (10YR 3/2); silt loam; moderate medium and fine subangular blocky structure breaking to fine subangular blocky and granular structure; friable; many fine roots; pH 7.3; abrupt smooth boundary.
A21	8-12"	Dark grayish brown (10YR 4/2) exteriors and dark brown to olive brown (1Y 4/3) interiors, kneaded dark grayish brown (1Y 4/2), light brownish gray (10YR 6/2) grainy silt coatings on peds when dry; silt loam; moderate medium platy structure breaking to fine and medium subangular blocky; friable; many fine roots; pH 5.7; gradual smooth boundary.
B1	12-16"	Dark grayish brown (10YR 4/2) exteriors and brown (10YR 4/3) interiors of peds, kneaded brown to olive brown (10YR 4/3 to 2.5Y 4/4), light brownish gray (10YR 6/1 and 6/2) grainy silt coatings on peds when dry; silty clay loam; moderate medium and fine subangular blocky structure breaking to fine subangular blocky; friable; few fine roots; pH 5.0; clear smooth boundary.
B21	16-23"	Grayish brown (10YR 5/2) exteriors and dark grayish brown (2.5Y 4/2-4/3) interiors, continuous light brownish gray (10YR 6/1-6/2) grainy silt coatings on peds when dry, kneaded dark brown to olive broan (10YR 4/3-2.5Y 4/4); silty clay loam; moderate medium and fine subangular blocky structure; friable to slightly firm; few fine soft dark reddish brown (5YR 2/2) Mn oxide concretions; few fine roots; pH 5.0; clear smooth boundary.

B22	23-29"	Grayish brown (2.5Y 5/2) exteriors and interiors mottled 60% grayish brown (2.5Y 5/2) and 40% light olive brown (2.5Y 5/4 and 5/6), nearly continuous light gray (10YR 6/1 and 7/1) grainy silt coatings on peds when dry, kneaded brown to light olive brown (10YR 5/3-2.5Y 5/4); silty clay loam; moderate medium and fine subangular blocky structure; friable to slightly firm; common fine soft dark reddish brown (5YR 2/2) Mn oxide concretions; few fine roots; pH 5.1; clear smooth boundary.
B23	29-34"	Grayish brown (2.5Y 5/2) exteriors and interiors mottled 50% yellowish brown (10YR 5/6), 30% light brownish gray (10YR 6/2) and 20% light olive brown (2.5Y 5/6), discontinuous light brownish gray (10YR 6/2) grainy silt coats on peds when dry, kneaded brown to light olive brown (10YR 5/3 to 2.5Y 5/4); silty clay loam; moderate medium angular and subangular blocky structure; friable to slightly firm; common fine soft dark reddish brown (5YR 2/2) Mn oxide concretions; few very dark gray (10YR 3/1) clay filled channels; few fine roots; pH 5.2; abrupt wavy boundary.
IIB31	34-36"	Matrix yellowish brown (10YR 5/6) with common medium distinct light olive gray (5Y 6/2) and few medium faint light olive brown (2.5Y 5/6) mottles, nearly continuous grayish brown (10YR 5/2) silt coatings on prism faces, kneaded yellowish brown (10YR 5/6); heavy loam; weak medium prismatic structure breaking to medium and fine subangular blocky; slightly firm; few fine very dark gray (10YR 3/1) clay filled channels; common medium and fine soft dark reddish brown (5YR 2/2) Mn oxide concretions; pH 6.5; gradual smooth boundary.
IIB32	46-62"	Mottled 70% yellowish brown (10YR 5/6) and 30% olive yellow (2.5Y 6/6) with few fine faint light brownish gray (2.5Y 6/2) mottles, kneaded yellowish brown (10YR 5/4); heavy loam; very weak medium subangular blocky structure; slightly firm; some cracks filled with very dark grayish brown (10YR 3/2) clay; high concentration of medium sand between 55 and 57 inches; pH 6.9; gradual smooth boundary.

IIC1	62-80"	Mottled 60% yellowish brown (10YR 5/6), 20% grayish brown (10YR 5/2) and 20% brownish yellow (10YR 6/6), kneaded yellowish brown (10YR 5/4); heavy loam; massive; slightly firm; few very dark grayish brown (10YR 3/2) clay streaks; pH 7.3; abrupt wavy boundary.
IIC2	80-96"	Matrix yellowish brown (10YR 5/4) with common fine distinct olive yellow (2.5Y 6/6) mottles, kneaded yellowish brown (10YR 5/5); loam; massive; slightly firm; several strong brown (7.5YR 5/6) iron enriched zones; calcareous with common fine soft white (10YR 8/0) $CaCO_3$ concretions; pH 8.1; diffuse boundary.
IIC2	96-112"+	Same as above; horizon subdivided for sampling; pH 8.1.

Waubeek silt loam (P732)

Location: Approximately 930 feet north and 550 feet west of the southeast corner of sec. 12, T 81 N, R 9 W, Iowa County, Iowa.

Slope and physiographic position: 2 percent, slightly convex ridgetop.

Described by: J. A. Kovar and J. D. Highland, August 1964.

Horizon	Depth	Description (moist Munsell colors)
A1p	0-7"	Very dark gray (10YR 3/1) with slight mixing of very dark grayish brown (10YR 3/2), crushes to 10YR 3/2; silt loam; moderate medium subangular blocky structure breaking to fine subangular blocky and granular; friable; many fine and medium roots; pH 7.2; abrupt smooth boundary.
A2	7-9½"	Mixed 60% dark grayish brown (10YR 4/2) and 40% very dark grayish brown (10YR 3/2) exteriors and dark brown (10YR 4/3) interiors, kneaded dark brown (10YR 3/3); silt loam; weak medium platy structure breaking to fine subangular blocky; friable; many fine and medium roots; pH 6.8; clear smooth boundary.
B1	9½-14"	Dark yellowish brown (10YR 4/4), kneaded dark brown (10YR 4/3), few thin discontinuous light brownish gray (10YR 6/2) silty ped coatings when dry; silty clay loam; moderate medium subangular blocky structure; friable; many fine and medium roots; pH 6.1; gradual smooth boundary.
B21	14-23"	Exteriors brown (10YR 5/3) and interiors yellowish brown (10YR 5/4), discontinuous light brownish gray (10YR 6/2) silty ped coatings when dry, kneaded yellowish brown (10YR 5/4); silty clay loam; moderate medium subangular blocky structure breaking to fine subangular blocky; friable; few fine soft dark reddish brown (5YR 2/2) Mn oxide concretions; many fine roots; pH 5.3; clear smooth boundary.
B22	23-31"	Exteriors brown (10YR 5/3) and interiors yellowish brown (10YR 5/4 and 5/6), discontinuous light brownish gray (10YR 6/2) silty ped coatings when dry, kneaded yellowish brown (10YR 5/4); light silty clay loam; moderate medium (but coarser than above) subangular blocky; friable; common fine soft dark reddish brown (5YR 2/2) Mn oxide concretions; few fine roots; pH 5.2; abrupt wavy boundary.

IIB23	31-41"	Exteriors yellowish brown (10YR 5/4) (mostly vertical prism faces) and interiors yellowish brown (10YR 5/6) with few medium distinct strong brown (7.5YR 5/6) and few fine faint brown (10YR 5/3) mottles, kneaded yellowish brown (10YR 5/6); light gray (10YR 7/1) sand-coated prism faces in upper part of horizon and discontinuous brown and dark brown (10YR 4/2 and 5/2) clay films in lower part of horizon; light sandy clay loam; moderate medium prismatic structure breaking to medium and fine subangular blocky; slightly firm; few fine soft dark reddish brown (5YR 2/2) Mn oxide concretions and few fine hard white (10YR 8/0) SiO_2 concretions; few fine roots; pH 5.2; gradual smooth boundary.
IIB3	41-55"	Mottled 50% yellowish brown (10YR 5/6), 30% grayish brown (2.5Y 5/2) and 20% strong brown (7.5YR 5/6), kneaded yellowish brown (10YR 5/4); light sandy clay loam; very weak medium subangular blocky structure; slightly firm; common fine soft dark reddish brown (5YR 2/2) oxide concretions; pH 5.9; gradual smooth boundary.
IIC1	55-72"	Matrix yellowish brown (10YR 5/4) with many fine faint strong brown (7.5YR 5/6) and few fine faint grayish brown (10YR 5/2) mottles, kneaded yellowish brown (10YR 5/4); light sandy clay loam; massive structure; slightly firm; few small very dark grayish brown (10YR 3/2) clay filled cracks and channels; few fine soft dark reddish brown (5YR 2/2) and dark brown (7.5YR 3/2) Mn oxide concretions; pH 7.0; abrupt wavy boundary.
IIC2	72-85"	Matrix brown (10YR 5/3) with common fine distinct strong brown (7.5YR 5/6) mottles, kneaded yellowish brown (10YR 5/4); light sandy clay loam; massive structure; slightly firm; few fine soft dark reddish brown (5YR 2/2) Mn oxide concretions and thin zones of strong brown (7.5YR 5/6) Fe concentrations; calcareous with few fine soft white (10YR 8/0) $CaCO_3$ concretions; pH 7.9; diffuse boundary.
IIC2	85-98"	Same as above; horizon divided for sampling; zone of $CaCO_3$ concentration from 95 to 96 inches; pH 7.9.

IIC3 98-122"+ Matrix brown (10YR 5/3) with few fine faint light gray (2.5Y 7/2) and few fine faint yellowish brown (10YR 5/6) mottles, kneaded pale brown (10YR 6/3); sandy loam; massive structure; slightly firm; few fine soft dark reddish brown (5YR 2/2) Mn oxide concretions; several zones of strong brown (7.5YR 5/6) Fe oxide concentration; calcareous with few fine soft white (10YR 8/0) $CaCO_3$ concretions; pH 8.1.

Maxfield silty clay loam (P733)

Location: 150 feet west and 160 feet north of the southeast corner of the NE¼ sec. 28, T 84 N, R 6 W, Linn County, Iowa.

Slope and physiographic position: 1 percent, slightly concave head of drainageway.

Described by: J. A. Kovar and J. D. Highland, August 1964.

Horizon	Depth	Description (moist Munsell colors)
A1p	0-8"	Black (N 2/0), crushes to black (10YR 2/1); silty clay loam; moderate medium to fine subangular blocky structure breaking to fine subangular blocky and fine granular; friable; many fine and medium roots; pH 7.1; clear smooth boundary.
A12	8-17"	Black (N 2/0), crushes to black (10YR 2/1); silty clay loam; moderate medium to fine subangular blocky structure breaking to fine subangular blocky; friable; few fine and medium roots; pH 6.6; clear smooth boundary.
A3	17-24"	Mixed colors, 60% very dark gray (5Y 3/1) and 40% dark grayish brown (2.5Y 4/2) with few fine faint light olive brown (2.5Y 5/4) mottles, crushes to very dark grayish brown (2.5Y 3/2); silty clay loam; weak fine and medium subangular blocky structure breaking to fine subangular blocky; friable; few fine dark reddish brown (5YR 2/2) Mn oxide concretions; slightly gleyed; pH 6.7; clear smooth boundary.
B2g	24-34"	Mottled, 60% olive gray (5Y 4/2), 30% light olive brown (2.5Y 5/6) and 10% yellowish brown (10YR 5/8) with some dark gray (5Y 4/1) discontinuous silty ped coatings, crushes to olive (5Y 5/3); light silty clay loam; weak medium and fine subangular blocky structure; friable to slightly firm; many fine dark reddish brown (5YR 2/2) Mn oxide concretions; pH 7.0; abrupt wavy boundary.
IIB31	34-37"	Mottled 60% yellowish brown (10YR 5/8) and 40% light olive brown (2.5Y 5/4), crushes to light olive brown (2.5Y 5/6); sandy loam; very weak medium subangular blocky structure; very friable few 1/4- to 1- inch pebbles; pH 7.[illegible]; abrupt wavy boundary.

IIB32	37-48"	Mottled 60% yellowish brown (10YR 5/8) and 40% light brownish gray (2.5Y 6/2), crushes to light yellowish brown (2.5Y 6/4); heavy sandy loam; very weak medium subangular blocky structure; slightly firm; light brownish gray (10YR 5/8) sand lens from 47 to 48 inches; pH 7.9; clear smooth boundary.
IIC1	48-64"	Mottled 40% olive yellow (2.5Y 6/8), 40% light brownish gray (2.5Y 6/2), and 20% brownish yellow (10YR 6/8), crushes to yellowish brown (10YR 5/8); loam; massive structure; slightly firm; few fine soft dark reddish brown (5YR 2/2) Mn oxide concretions; calcareous with common soft white (10YR 8/1) $CaCO_3$ concretions; pH 8.1; diffuse boundary.
IIC2	64-80"	Mottled 40% light brownish gray (2.5Y 6/2), 30% brownish yellow (10YR 6/8), and 30% olive yellow (2.5Y 6/8); loam; massive structure; firm; several pockets of yellowish brown (10YR 5/8) sand; few medium Fe concretions; calcareous; pH 8.2.
IIC2	80-97"+	Same as above; horizon divided for sampling; pH 8.2.
IIC3	97-106"+	Dark gray (5Y 4/1) loam; unoxidized unleached till; pH 8.1.

Remarks: Water table encountered at 40 inches below the surface.

Maxfield silty clay loam (P734)

Location: Linn County, Iowa; 1506 feet south and 36 feet west of the NE corner of the NW¼ sec. 30, T 85 N, R 6 W.

Slope and physiographic position: 1/2 percent to east, slightly concave head of drainageway.

Described by: J. A. Kovar, June 1965.

Horizon	Depth	Description (moist Munsell colors)
A1p	0-7"	Black (N 2/0) crushes to black (10YR 2/1), light silty clay loam; moderate medium and fine subangular blocky and fine granular structure breaking to fine subangular blocky and granular; friable; abundant fine and medium roots; pH 6.8; clear smooth boundary.
A12	7-13"	Black (N 2/0), crushes to black (10YR 2/1), silty clay loam; moderate medium subangular blocky structure breaking to fine subangular blocky and granular; friable; abundant fine and medium roots; pH 6.9; gradual smooth boundary.
A13	13-20"	Black (N 2/0), crushes to black (10YR 2/1); silty clay loam; moderate medium and coarse subangular blocky structure breaking to fine subangular blocky; friable; many fine and medium roots; few shiny fine sand grains; pH 7.1; gradual smooth boundary.
A3	20-25"	Black (10YR 2/1), crushes to very dark gray (10YR 3/1) with few fine faint dark grayish brown (2.5Y 4/2) mottles; clay loam; moderate medium subangular blocky structure breaking to fine subangular blocky; friable; few shiny fine sand grains; few fine roots; pH 7.1; clear smooth boundary.
B2g	25-33"	Mixed colors, 50% dark gray (5Y 4/1), 30% light olive brown (2.5Y 5/6), and 20% very dark grayish brown (2.5Y 3/2), kneaded very dark grayish brown (2.5Y 3/2) with few dark gray (N 4/0) discontinuous ped coatings; light clay loam; moderate medium subangular blocky; friable; few shiny fine sand grains; few fine roots; pH 7.6; clear wavy boundary.

IIB31	33-38"	Mottled, 50% yellowish brown (10YR 5/6), 30% yellowish brown (10YR 5/4), and 20% light olive brown (2.5Y 5/4), crushes to yellowish brown (10YR 5/6); heavy sandy loam; weak medium subangular blocky and granular; very friable; thin coarse sand lens at 38 inches, few fine soft dark reddish brown (5YR 2/2) manganese oxide concretions; pH 7.7; clear smooth boundary.
IIB32	38-48"	Mottled, 70% yellowish brown (10YR 5/6) and 30% brown (10YR 5/3), crushes to yellowish brown (10YR 5/5); medium loam; moderate medium subangular blocky; friable to slightly firm; many fine soft dark reddish brown (5YR 2/2) manganese oxide concretions; pH 8.2; gradual smooth boundary.
IIC1	48-62"	Mottled, 70% yellowish brown (10YR 5/5) and 30% light gray (10YR 6/1), crushes to yellowish brown (10YR 5/4); medium loam; weak medium and coarse subangular blocky to massive; slightly firm; few fine soft dark reddish brown (5YR 2/2) manganese oxide concretions; calcareous with many fine soft $CaCO_3$ concretions and $CaCO_3$ in cracks; pH 8.1; gradual smooth boundary.
IIC2	62-74"	Mottled, 60% yellowish brown (10YR 5/6), 30% light gray (10YR y/1) and 10% brown (7.5YR 5/4), crushes to yellowish brown (10YR 5/4); medium loam; massive; slightly firm; few fine soft dark reddish brown (5YR 2/2) manganese oxide concretions; calcareous with few fine soft $CaCO_3$ concretions and some $CaCO_3$ in cracks; pH 8.2; diffuse smooth boundary.
IIC2	74-86"	Same as above - subdivided for sampling; pH 8.2.
IIC2	86-101"	Same as above - subdivided for sampling; pH 8.3.
IIC3	101-117"	Mottled, 50% light brownish gray (10YR 6/2), 40% yellowish brown (10YR 5/6), and 10% brown (7.5YR 5/4), crushes to yellowish brown (10YR 5/4); heavy loam; massive; slightly firm; few fine soft dark reddish brown (5YR 2/2) manganese oxide concretions; calcareous with few fine soft $CaCO_3$ concretions; pH 8.3; gradual smooth boundary.
IIC4	117-125"	Mixed colors, 90% very dark grayish brown (2.5Y 3/2) and 10% yellowish brown (10YR 5/6); heavy loam; deoxidized unleached till; some yellowish red (5YR 4/6) iron segregations; massive; slightly firm; calcareous with some soft $CaCO_3$ concretions; pH 8.3; diffuse smooth boundary.

IIC5	125-131"	Yellowish brown (10YR 5/8) with few fine faint light brownish gray (10YR 6/2) mottles; some yellowish red (5YR 4/6) iron segregations; heavy loam; oxidized till; massive; slightly firm; calcareous with some soft $CaCO_3$ concretions; pH 8.3; diffuse smooth boundary.
IIC6	131-148"	Mixed colors, 60% very dark grayish brown (2.5Y 3/2), 40% light olive brown (2.5Y 5/4); heavy loam; unoxidized unleached till with occasional thin yellowish brown (10YR 5/8) streaks and few fine organic flecks; massive; slightly firm; calcareous with some soft $CaCO_3$ concretions; pH 8.2; diffuse smooth boundary.
IIC6	148-172"	Same as above - subdivided for sampling; pH 8.1.
IIC7	172-184"+	Very dark gray (5Y 3/1) with few medium faint light olive brown (2.5Y 5/6) mottles; heavy loam; unoxidized unleached till; massive; firm; few fine organic flecks; calcareous; pH 8.1.

Waubeek silt loam (P735)

Location: 141 feet north and 18 feet east of the northwest corner of the SW¼ sec. 24, T 83 N, R 8 W, Linn County, Iowa.

Slope and physiographic position: 1 1/2 percent, broad slightly convex ridge.

Described by: J. A. Kovar, June 1965.

Horizon	Depth	Description (moist Munsell colors)
A1p	0-6"	Very dark gray (10YR 3/1) crushes to very dark grayish brown (10YR 3/2); silt loam; moderate medium and fine fine subangular blocky structure breaks to fine subangular blocky and granular; friable; many fine and medium roots; pH 7.1; clear smooth boundary.
A21	6-9"	Ped exteriors very dark grayish brown (10YR 3/2) and interiors dark grayish brown (10YR 4/2), kneaded 10YR 3/2; silt loam; weak medium subangular blocky to weak fine platy structure breaks to fine subangular blocky; friable; many fine and medium roots; pH 6.9; clear smooth boundary.
A22	9-14"	Ped exteriors dark grayish brown (10YR 4/2) and interiors very dark grayish brown (10YR 3/2), kneaded 10YR 3/2; silt loam; weak fine subangular blocky to weak fine platy structure breaks to fine subangular blocky; friable; some thin discontinuous grainy silt coatings, light brownish gray (10YR 6/2) when dry; many fine and medium roots; pH 6.4; gradual smooth boundary.
B1	14-21"	Ped exteriors brown (10YR 5/3) and interiors yellowish brown (10YR 5/4), kneaded 10YR 5/4, with few thin discontinuous grainy silt coatings light brownish gray (10YR 6/2) when dry; light silty clay loam; moderate medium subangular blocky structure, greaks to fine subangular blocky; friable; many fine roots; pH 5.5; gradual smooth boundary.

B21	21-28"	Ped exteriors brown (10YR 5/3) and interiors yellowish brown (10YR 5/4), kneaded 10YR 5/4, with few thin discontinuous grainy silt coatings, light brownish gray (10YR 6/2) when dry; light silty clay loam; moderate medium subangular blocky structure breaks to fine subangular blocky; friable; few fine soft dark reddish brown (5YR 2/2) manganese concretions; many fine roots; pH 5.0; gradual smooth boundary.
B22	28-32"	Ped exteriors light yellowish brown (10YR 6/4), interiors yellowish brown (10YR 5/4), crushes to yellowish brown (10YR 5/4), almost continuous thin light brownish gray (10YR 6/2) grainy silt coatings when dry; light silty clay loam; moderate medium subangular blocky breaks to fine subangular blocky structure; friable; few fine soft dark manganese concretions; many fine and medium roots; pH 5.0; clear wavy boundary.
IIB23	32-38"	Exteriors yellowish brown, interiors yellowish brown (10YR 5/6), crushes to yellowish brown (10YR 5/6); heavy loam; few fine faint strong brown (7.5YR 5/6) mottles; moderate medium prismatic breaks to medium and fine subangular blocky structure; slightly firm; few thin discontinuous dark grayish brown (10YR 4/2) clay coatings; almost continuous light brownish gray (10YR 6/2, dry) sand coatings on prism faces; few fine dark manganese concretions; few fine roots; pH 5.1; gradual wavy boundary.
IIB31	38-44"	Yellowish brown (10YR 5/4), kneads to yellowish brown (10YR 5/6); heavy loam; few fine faint light brownish gray (10YR 6/2) and strong brown (7.5YR 5/6) mottles; moderate medium prismatic breaks to medium and fine subangular blocky structure; slightly firm; few discontinuous grayish brown (10YR 5/2) clay coatings and accumulations in cracks; few soft dark Mn concretions; few fine soft Fe accumulations; few hard white (SiO_2) concretions; pH 5.1; gradual smooth boundary.
IIB32	44-54"	Yellowish brown (10YR 5/6) heavy loam; few fine faint light brownish gray (10YR 6/2) and strong brown (7.5YR 5/6) mottles; weak medium subangular blocky structure; slightly firm; many fine soft dark Mn concretions and some Mn coatings on peds; few discontinuous dark grayish brown (10YR 4/2) clay coatings; thin medium sand lens at 53 inches; pH 5.5; gradual smooth boundary.

IIC1	54-67"	Yellowish brown (10YR 5/4) heavy loam; few fine faint light brownish gray (10YR 6/2) and strong brown (7.5YR 5/6) mottles; massive; slightly firm; few thin discontinuous dark grayish brown (10YR 4/2) clay coatings; many fine soft Mn concretions; pH 6.2; diffuse smooth boundary.
IIC2	67-81"	Same as above; subdivided for sampling; pH 7.2; abrupt wavy boundary.
IIC3	81-92"	Mixed colors, 60% yellowish brown (10YR 5/4) and 40% light brownish gray (10YR 6/2), kneads to yellowish brown (10YR 5/6); heavy loam; few fine faint strong brown (7.5YR 5/6) mottles; massive; firm; thin light brownish gray (10YR 6/2) silt wedge at 86 inches; few fine soft Mn concretions; calcareous; pH 8.2; gradual smooth boundary.
IIC3	92-104"+	Mixed colors, 70% light brownish gray (10YR 6/2) and 30% yellowish brown (10YR 5/6), kneads to pale brown (10YR 6/3); heavy loam (deoxidized till); few fine faint strong brown (7.5YR 5/6) mottles; massive; firm; few small Fe concentrations; calcareous; pH 8.1.

Unnamed (282F) silt loam (P736)

Location: Clay County, Iowa; 8 feet north and 950 feet west of the northeast corner of the SE¼ SE¼ sec. 20, T 94 N, R 36 W.

Slope and physiographic position: Less than 1 percent, broad upland area.

Described by: J. A. Kovar, August 1965.

Horizon	Depth	Description (moist Munsell colors)
A1	0-6"	Black (10YR 2/1) silt loam; moderate fine subangular blocky and fine granular structure; friable; abundant fine and medium roots; pH 5.3; clear smooth boundary.
A21	6-11"	Very dark gray (10YR 3/1) with thin continuous light gray (10YR 6/1) silty ped coatings when dry, kneaded dark gray (10YR 4/1); silt loam; moderate fine platy breaks to fine subangular blocky and granular structure; friable; abundant fine and medium roots; pH 5.2; gradual smooth boundary.
A22	11-19"	Very dark gray (10YR 3/1) with thin discontinuous light gray (10YR 6/1) silty ped coatings when dry, kneaded very dark grayish brown (10YR 4/2); silty clay loam; moderate medium and fine subangular blocky breaks to fine subangular blocky and granular structure; friable; plentiful fine and medium roots; pH 5.1; clear smooth boundary.
B1	19-24"	Mixed colors 60% very dark grayish brown (10YR 3/2) and 40% yellowish brown (10YR 5/4) with almost continuous thin dark grayish brown (10YR 4/2) clay coatings, kneaded dark brown (10YR 4/3); silty clay loam; moderate medium subangular blocky breaks to fine subangular blocky structure; friable; few fine and medium roots; pH 5.3; gradual smooth boundary.
B21	24-30"	Exteriors dark grayish brown (10YR 4/2) clay coatings, interiors brown (10YR 5/3) with common fine faint light brownish gray (10YR 6/2) mottles, kneaded brown (10YR 5/3); silty clay loam; moderate medium to coarse subangular blocky breaks to fine and medium subangular blocky structure; slightly firm; some clay accumulation in cracks and root channels; few medium and coarse roots; pH 5.3; clear wavy boundary.

IIB22	30-35"	Exteriors very dark grayish brown (10YR 3/2) thick clay coatings, interiors brown (10YR 5/3), some very dark gray (10YR 3/1) clay accumulation in cracks and root channels; heavy clay loam (till); weak medium and coarse subangular blocky structure; slightly firm; few medium and coarse roots; pH 5.5; gradual smooth boundary.
IIB23	35-39"	Same as above horizon except ped coatings thinner and discontinuous; structure is very weak to massive; pH 6.3.
IIC1	39-47"	Mottled colors 40% gray (10YR 6/1) and 60% light yellowish brown (2.5Y 6/4); light clay loam; massive; firm; calcareous with few soft calcium carbonate concretions; pH 7.7; diffuse boundary.
IIC2	47-54"	Colors same as above horizon; eight clay loam; massive; firm; calcareous with many fine and medium soft calcium carbonate concretions; pH 7.9; diffuse boundary.
IIC2	54-60"+	Same as above horizon; subdivided for sampling; pH 7.9.

Unnamed (282) silty clay loam (P737)

Location: O'Brien County, Iowa; 760 feet west and 310 feet north of the southeast corner of sec. 15, T 96 N, R 40 W.

Slope and physiographic position: 1 1/2 percent, broad, slightly convex upland slope.

Described by: J. A. Kovar, August 1965.

Horizon	Depth	Description (moist Munsell colors)
A1p	0-7"	Black (10YR 2/1) crushes to very dark gray (10YR 3/1); silty clay loam; moderate fine and medium subangular blocky breaks to fine subangular blocky and granular structure; friable; many fine roots; pH 5.7; gradual smooth boundary.
A12	7-14"	Black (10YR 2/1) crushes to very dark gray (10YR 3/1); silty clay loam; moderate medium subangular blocky breaks to fine subangular blocky structure; friable; many fine roots; pH 6.7; gradual smooth boundary.
A3	14-20"	Very dark gray (10YR 3/1) crushes to very dark grayish brown (10Y 3/2); silty clay loam; moderate medium subangular blocky breaks to fine subangular blocky structure; friable; many fine and medium roots; pH 7.0; gradual smooth boundary.
B1	20-27"	Very dark grayish brown (2.5Y 3/2) with few fine faint light olive brown (2.5Y 5/4) mottles, crushes to dark grayish brown (2.5Y 4/2); silty clay loam; moderate medium subangular blocky breaks to fine subangular blocky structure; friable; many fine and medium roots; pH 7.3; clear wavy boundary.
B2	27-32"	Mottled 60% dark grayish brown (2.5Y 4/2) and 40% light olive brown (2.5Y 5/4), crushes to olive brown (2.5Y 4/4); silt loam; moderate medium subangular blocky breaks to fine subangular blocky structure; friable to slightly firm; calcareous with few soft white calcium carbonate concretions; pH 7.8; clear wavy boundary.

IIC1	32-40"	Light olive brown (2.5Y 5/4) to light yellowish brown (10YR 6/4) with few fine faint grayish brown (2.5Y 5/2) mottles; light clay loam till; massive; firm; few pebbles at top of horizon; thin sand wedge at 37 inches; calcareous with many fine and medium soft calcium carbonate concretions; pH 8.0; abrupt wavy boundary.
IIC2	40-49"	Olive yellow (2.5Y 6/4) to light yellowish brown (10YR 6/4) with few fine faint light brownish gray (10YR 6/2) and yellowish brown (10YR 5/6) mottles; light clay loam till; massive; firm; some iron segregations; calcareous with few fine soft calcium carbonate concretions; pH 8.0; diffuse boundary.
IIC3	49-60"+	Light yellowish brown (10YR 6/4) with few fine faint light brownish gray (10YR 6/2) and yellowish brown (10YR 5/6) mottles; light clay loam; massive; firm; calcareous with few fine soft calcium carbonate concretions; pH 8.1; thin very fine sand wedge at 56 inches.

Unnamed (191) silty clay loam (P738)

Location: O'Brien County, Iowa; 490 feet west and 360 feet north of the southeast corner of the NE¼ sec. 1, T 97 N, R 41 W.

Slope and physiographic position: 0 percent, broad level upland area.

Described by: J. A. Kovar, August 1965.

Horizon	Depth	Description (moist Munsell colors)
A1p	0-7"	Black (N 2/0), crushes to black (10YR 2/1); silty clay loam; moderate fine and medium subangular blocky breaks to fine subangular blocky and granular structure; friable; many fine and medium roots; pH 6.7; gradual smooth boundary.
A12	7-14"	Black (N 2/0), crushes to black (10YR 2/1); silty clay loam; moderate fine and medium subangular blocky breaks to fine subangular blocky and granular structure; friable; many fine and medium roots; pH 6.7; gradual smooth boundary.
A3	14-20"	Mixed colors 70% black (10YR 2/1) and 30% light olive brown (2.5Y 5/4), crushes to very dark gray (10YR 3/1); silty clay loam; moderate medium and fine subangular blocky breaks to fine subangular blocky and granular structure; friable; many fine and medium roots; pH 6.8; clear smooth boundary.
B1	20-25"	Mixed colors black (10YR 2/1) and light olive brown (2.5Y 5/4) with common fine faint light brownish gray (10YR 6/2) mottles, crushes to olive brown (2.5Y 4/4); silty clay loam; moderate medium subangular blocky breaks to fine subangular blocky structure; friable; few fine shiny sand grains; few fine and medium roots; pH 7.2; gradual smooth boundary.
B2	25-32"	Light olive brown (2.5Y 5/4) with common fine faint light brownish gray (10YR 6/2) and yellowish brown (10YR 5/6) mottles; some very dark gray (10YR 3/1) clay accumulations in cracks and pores; silty clay loam; weak medium subangular blocky structure; friable to slightly firm; pH 7.4; clear wavy boundary.

IIB3	32-38"	Mottled 50% light yellowish brown (2.5Y 6/4), 30% yellowish brown (10YR 5/6) and 20% light brownish gray, kneaded to light olive brown (2.5Y 5/4); some dark grayish brown (10YR 4/2) discontinuous clay coatings on peds; clay loam till; weak medium subangular blocky structure; firm; calcareous with few fine soft calcium carbonate concretions; pH 8.0; gradual smooth boundary.
IIC1	38-45"	Mottled 60% light brownish gray (2.5Y 6/2) and 40% olive yellow (2.5Y 6/6), kneads to light yellowish brown (2.5Y 6/4); clay loam; massive; firm; few strong brown (7.5YR 5/6) iron accumulations; calcareous with few soft fine and medium calcium carbonate concretions; pH 8.3; diffuse boundary.
IIC2	45-52"	Mottled 60% olive yellow (2.5Y 6/6) and 40% light brownish gray (10YR 6/2); light clay loam; massive; firm; some iron segregations; calcareous with few soft fine and medium calcium carbonate concretions; pH 8.4; diffuse boundary.
IIC2	52-60"+	Same as above; horizon subdivided for sampling; pH 8.3.

Unnamed (481) silt loam (P739)

Location: Linn County, Iowa; NE¼ NE¼ sec. 15, T 83 N, R 8 W.

Slope and physiographic position: 2 percent, slightly convex, broad sideslope.

Described by: J. A. Kovar, June 1965.

Horizon	Depth	Description (moist Munsell colors)
A1	0-5"	Very dark gray (10YR 3/1) crushes to 10YR 3/2; light silt loam; moderate fine subangular blocky structure breaks to fine subangular blocky and granular; friable; many fine and medium roots; pH 5.6; clear smooth boundary.
A21	5-9"	Dark gray (10YR 4/1) crushes to 10YR 4/2; fine silt coatings on peds, light brownish gray (10YR 6/2) dry; light silt loam; moderate thin platy structure; friable; many fine and medium roots; pH 5.4; gradual smooth boundary.
A22	9-13"	Ped exteriors dark grayish brown (10YR 4/2) and interiors brown (10YR 4/3), crushes to 10YR 4/3; fine silt coatings on peds; light brownish gray (10YR 6/2) when dry; light silt loam; weak thin platy structure; friable; many fine and medium roots; pH 5.1; gradual smooth boundary.
B1	13-20"	Ped exteriors brown (10YR 4/3) and interiors brown (10YR 5/3) crushes to 10YR 5/3) light brownish gray (10YR 6/2) dry; fine silt coatings on peds; silty clay loam; moderate fine and medium subangular blocky structure; friable; many fine and medium roots; pH 4.7; gradual smooth boundary.
B21	20-26"	Brown (10YR 5/3), crushes to 10YR 5/4 with light brownish gray (10YR 6/2, dry) fine silt coatings on peds; silty clay loam; moderate medium and fine subangular blocky structure; friable; few fine soft dark reddish brown (5YR 2/2) Mn concretions; few fine and medium roots; pH 4.5; gradual smooth boundary.

B22	26-33"	Brown (10YR 5/3) with some light brownish gray (10YR 6/2, dry) fine silt coatings on peds in upper part of horizon and some discontinuous dark grayish brown (10YR 4/2) clay films; silty clay loam; moderate medium and fine subangular blocky structure; friable; few fine soft dark reddish brown (5YR 2/2) Mn concretions; pH 4.5; clear wavy boundary.
IIB23	33-39"	Yellowish brown (10YR 5/4) with discontinuous thin dark grayish brown (10YR 4/3) clay films; sandy clay loam till; moderate medium subangular blocky structure; slightly firm; few fine soft dark reddish brown (5YR 2/2) Mn concretions; pH 4.7; gradual boundary.
IIB3	39-47"	Yellowish brown (10YR 5/6) with few fine faint light gray (10YR 6/1) and strong brown (7.5YR 5/6) mottles; almost continuous grayish brown (10YR 5/2) clay films; sandy clay loam; weak medium subangular blocky structure; slightly firm; few fine soft dark reddish brown (5YR 2/2) Mn concretions; pH 4.5; gradual boundary.
IIC1	47-57"	Yellowish brown (10YR 5/6) with few fine faint light gray (10YR 6/1) and strong brown (7.5YR 5/6) mottles; some grayish brown (10YR 5/2) and very dark grayish brown (10YR 3/2) clay films and accumulations in cracks; sandy clay loam; massive; slightly firm; abundant fine soft dark reddish brown (5YR 2/2) Mn concretions; pH 5.0; gradual boundary.
IIC2	57-68"	Yellowish brown (10YR 5/6) with few fine faint light gray (10YR 6/1) and strong brown (7.5YR 5/6) mottles; slightly firm; clay sandy loam; massive; abundant fine soft dark reddish brown (5YR 2/2) Mn concretions and some soft Fe accumulations; pH 5.7; diffuse boundary.
IIC3	68-79"	Colors mottled, 60% yellowish brown (10YR 5/6), 30% light olive gray (2.5Y 6/2) and 10% strong brown (7.5YR 5/6), kneaded color 10YR 5/4; sandy clay loam; massive; slightly firm; few soft dark reddish brown (5YR 2/2) Mn concretions; pH 6.9; clear boundary.
IIC3	79-90"	Same as above, subdivided for sampling; pH 7.1.

IIC4	90-105"	Colors mottled, 60% brownish yellow (10YR 6/6) and 40% light olive gray (2.5Y 6/2), kneaded color 10YR 6/4; sandy clay loam; massive; slightly firm; few soft dark reddish brown (5YR 2/2) Mn concretions; several thin zones of coarse silt; calcareous with many soft white $CaCO_3$ concretions; pH 7.8.
IIC4	105-120"+	Same as above, subdivided for sampling; pH 8.0.

Till I

Location: Road cut, east of highway no. 150, NW¼ NE¼ sec. 33, T 83 N, R 6 W, Linn County, Iowa.

Weathering zone[1]	Approximate depth below surface	Description (moist Munsell colors)
DU	30 feet	Mixed colors, 60% very dark grayish brown (2.5Y 3/2) and 40% light olive brown (2.5Y 5/6); loam; deoxidized, unleached till; some yellowish brown (10YR 5/8) streaks; massive; firm; calcareous with few soft $CaCO_3$ concretions; pH 8.3.
UU	40 feet	Very dark gray (5Y 3/1) with few faint light olive brown (2.5Y 5/6) mottles; loam; unoxidized, unleached till; massive; firm; calcareous, pH 8.1.
UU	50 feet	Very dark gray (5Y 3/1); loam; unoxidized, unleached till; massive; firm; few fine organic flecks; calcareous; pH 8.2.
UU	100 feet	Same as above, pH 8.1.

[1]DU = deoxidized, unleached; UU - unoxidized, unleached.

Till II

Location: Road cut immediately south and west of intersection of old Highway 30 and Highway 150, NW¼ NE¼ sec. 28, T 83 N, R 6 W, Linn County, Iowa.

Weathering zone[1]	Approximate depth below surface	Description (moist Munsell colors)
OL	5 feet	Mottled, 60% yellowish brown (10YR 5/6), 30% light gray (10YR 6/1) and 10% brown (7.5YR 5/4); crushes to yellowish brown (10YR 5/4); sandy clay loam; oxidized, leached till; massive; slightly firm; pH 8.3.
UU	20 feet	Very dark gray (5Y 3/2); loam; unoxidized, unleached till; massive; firm; few fine organic flecks; calcareous; pH 8.1.
UU	30 feet	Same as above, pH 8.1.

[1]OL = oxidized, leached; UU = unoxidized, unleached.

APPENDIX B: X-RAY DIFFRACTION PATTERNS

Figure 41. X-ray diffraction patterns for the $<1\mu$ clay fraction of the Dinsdale I and Sac I profiles

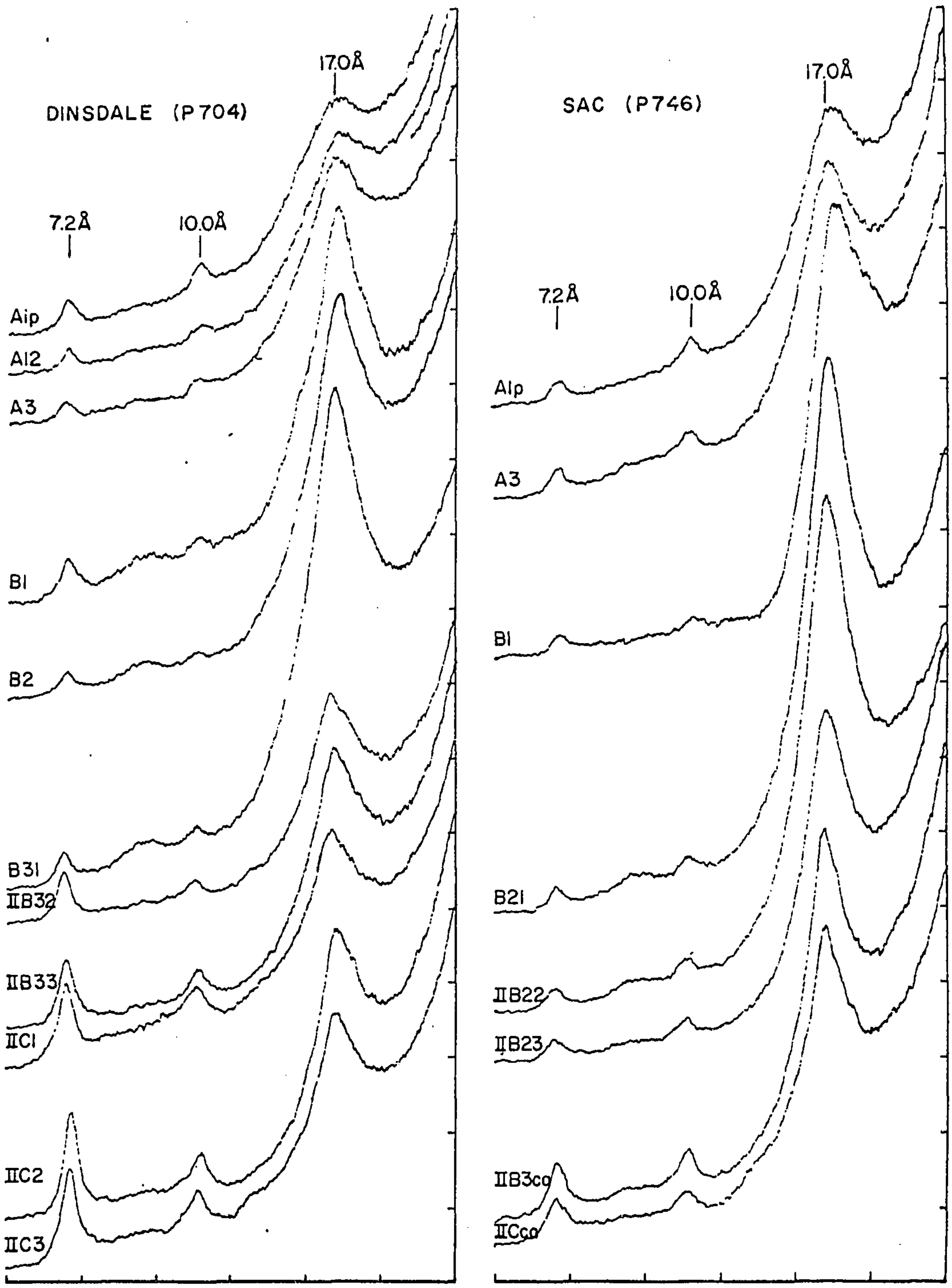

DINSDALE (P704)
7.2Å
10.0Å
17.0Å
Aip
A12
A3
B1
B2
B31
IIB32
IIB33
IIC1
IIC2
IIC3
SAC (P746)
7.2Å
10.0Å
17.0Å
Alp
A3
B1
B21
IIB22
IIB23
IIB3ca
IICca

Figure 42. X-ray diffraction patterns for the <1μ clay fraction of the Klinger II and Maxfield I profiles

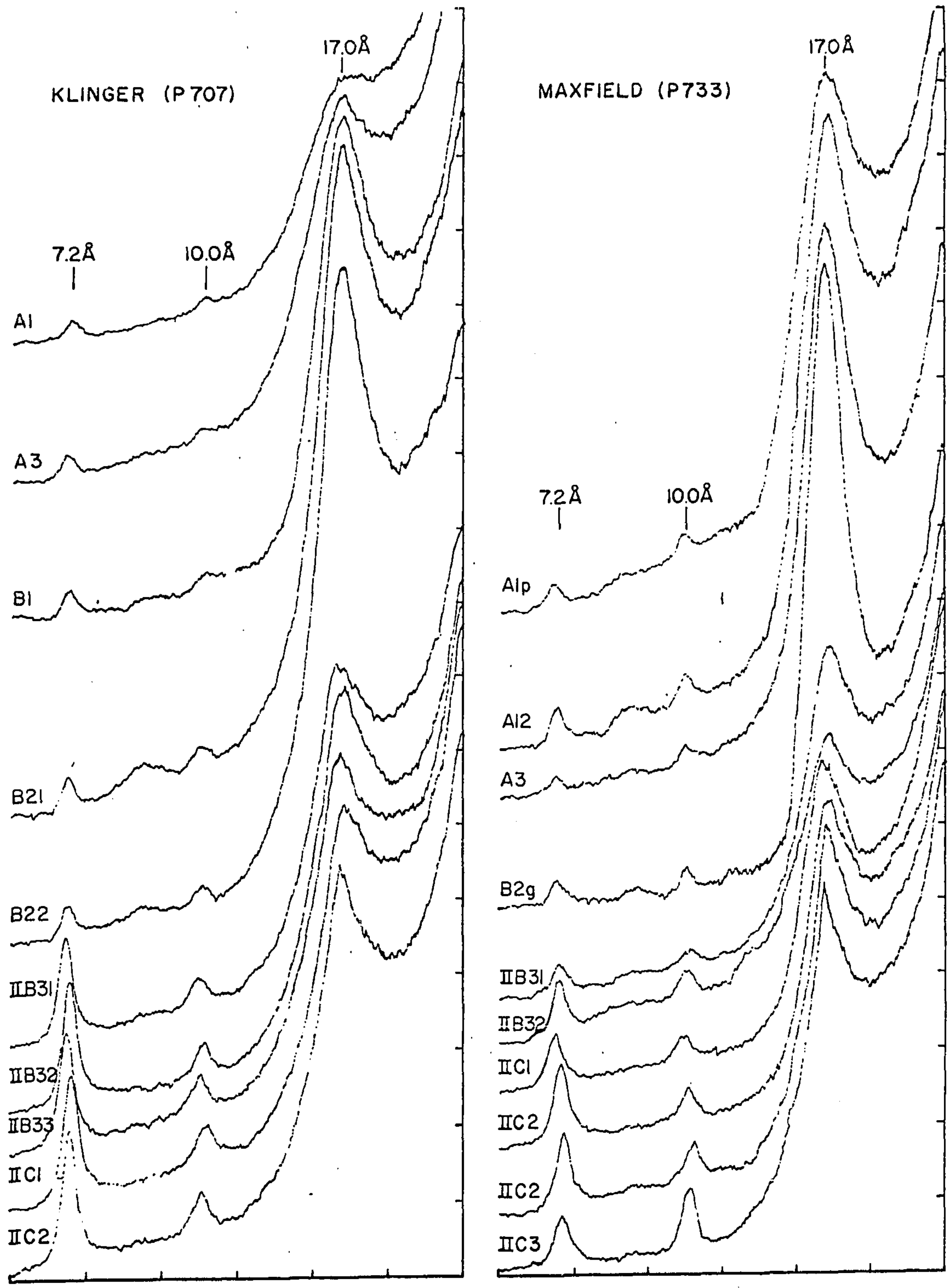

KLINGER (P707)
17.0Å
7.2Å
10.0Å
A1
A3
B1
B21
B22
IIB31
IIB32
IIB33
IIC1
IIC2
MAXFIELD (P733)
17.0Å
7.2Å
10.0Å
A1p
A12
A3
B2g
IIB31
IIB32
IIC1
IIC2
IIC2
IIC3

Figure 43. X-ray diffraction patterns for the $<1\mu$ clay fraction of selected horizons from Tama, Kenyon, P734 and Till I

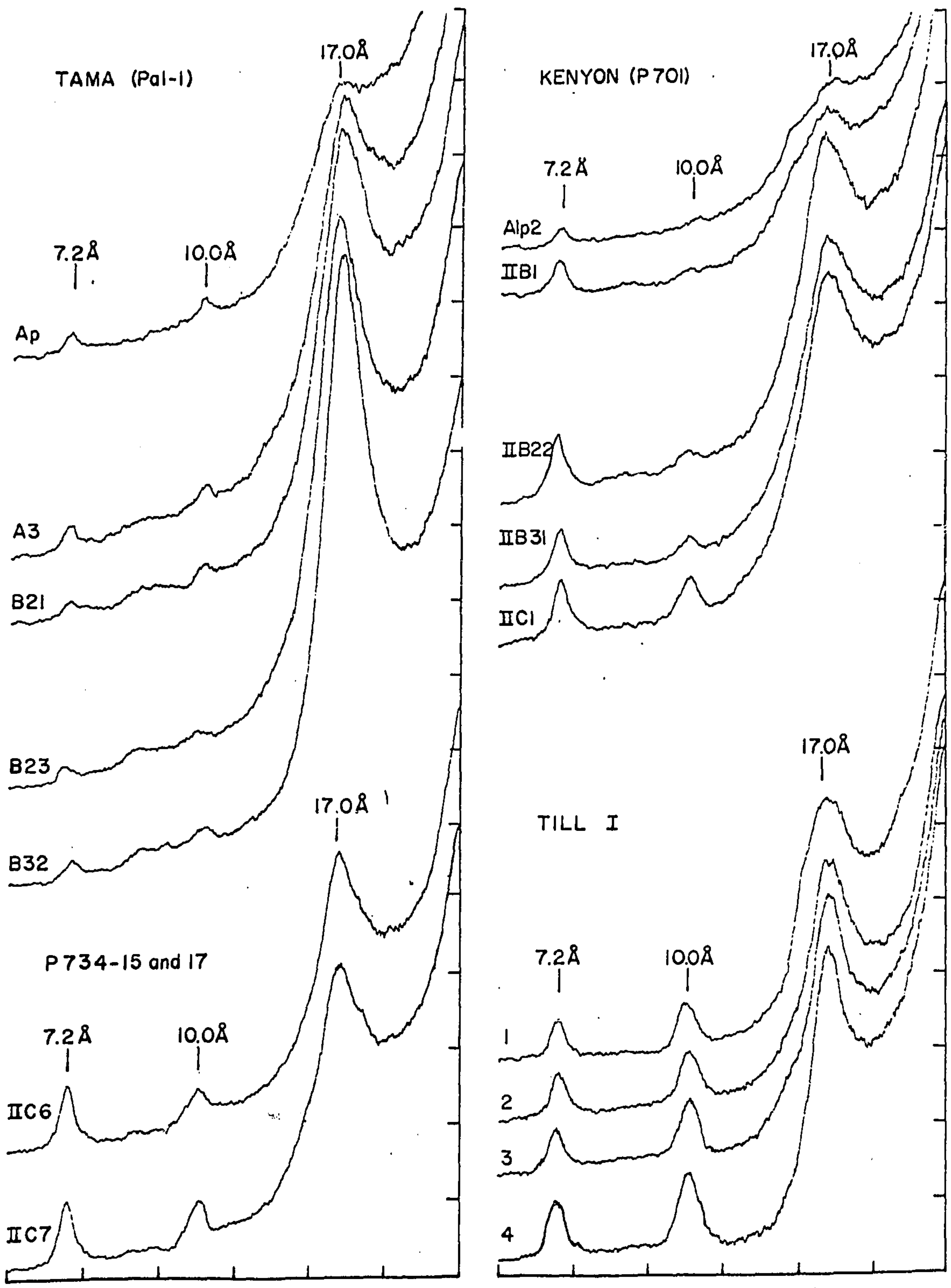
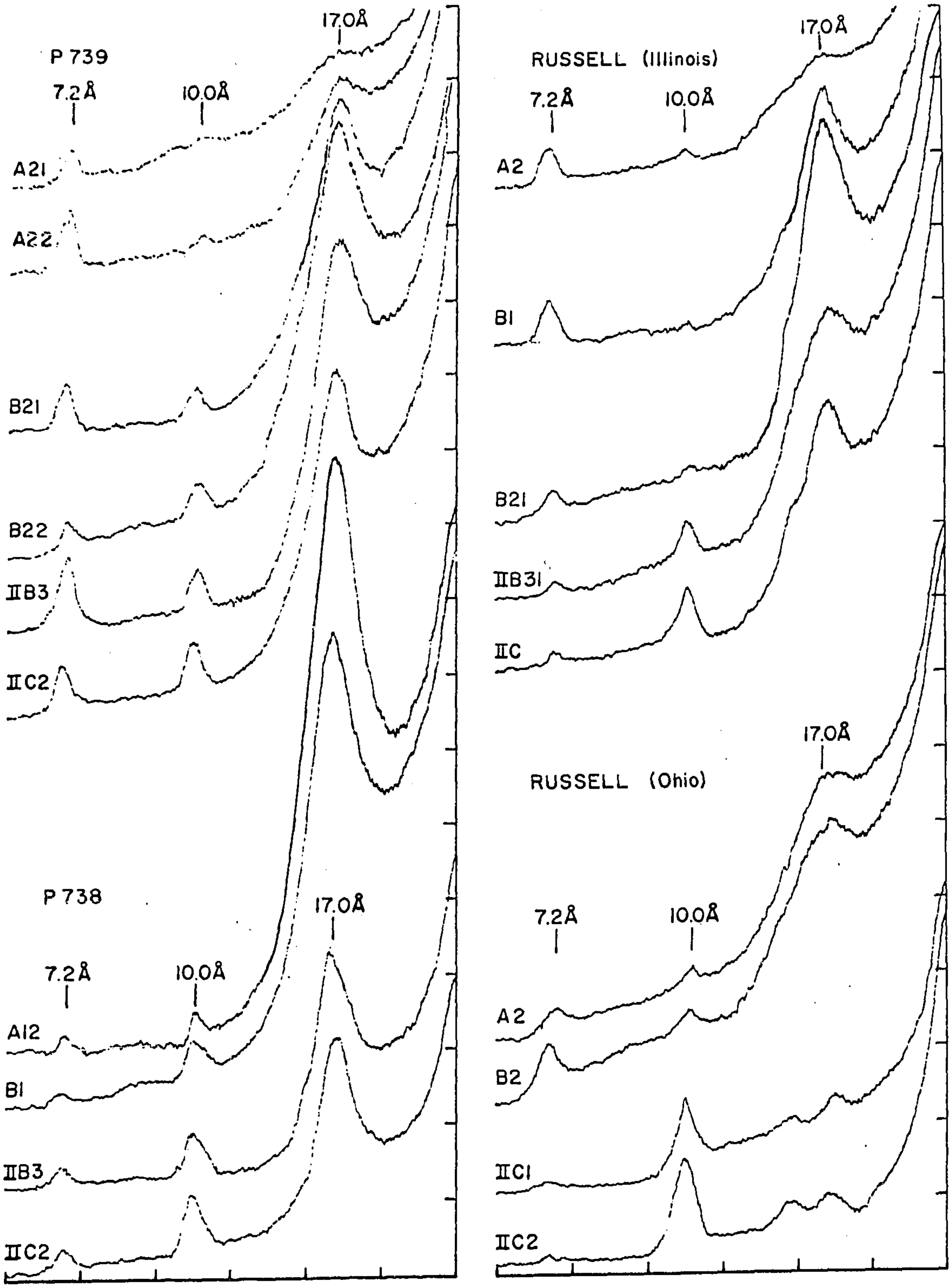

TAMA (Pal-1)
17.0Å
7.2Å
10.0Å
Ap
A3
B21
B23
B32
P734-15 and 17
17.0Å
7.2Å
10.0Å
IIC6
IIC7
KENYON (P701)
17.0Å
7.2Å
10.0Å
Alp2
IIB1
IIB22
IIB31
IIC1
TILL I
17.0Å
7.2Å
10.0Å
1
2
3
4

Figure 44. X-ray diffraction patterns for the $<1\mu$ clay fraction of selected horizons from P739, P738, Russell (Illinois) and Russell (Ohio)


P 739
7.2Å
10.0Å
17.0Å
A21
A22
B21
B22
IIB3
IIC2
P 738
7.2Å
10.0Å
17.0Å
A12
B1
IIB3
IIC2
RUSSELL (Illinois)
7.2Å
10.0Å
17.0Å
A2
B1
B21
IIB31
IIC
RUSSELL (Ohio)
7.2Å
10.0Å
17.0Å
A2
B2
IIC1
IIC2